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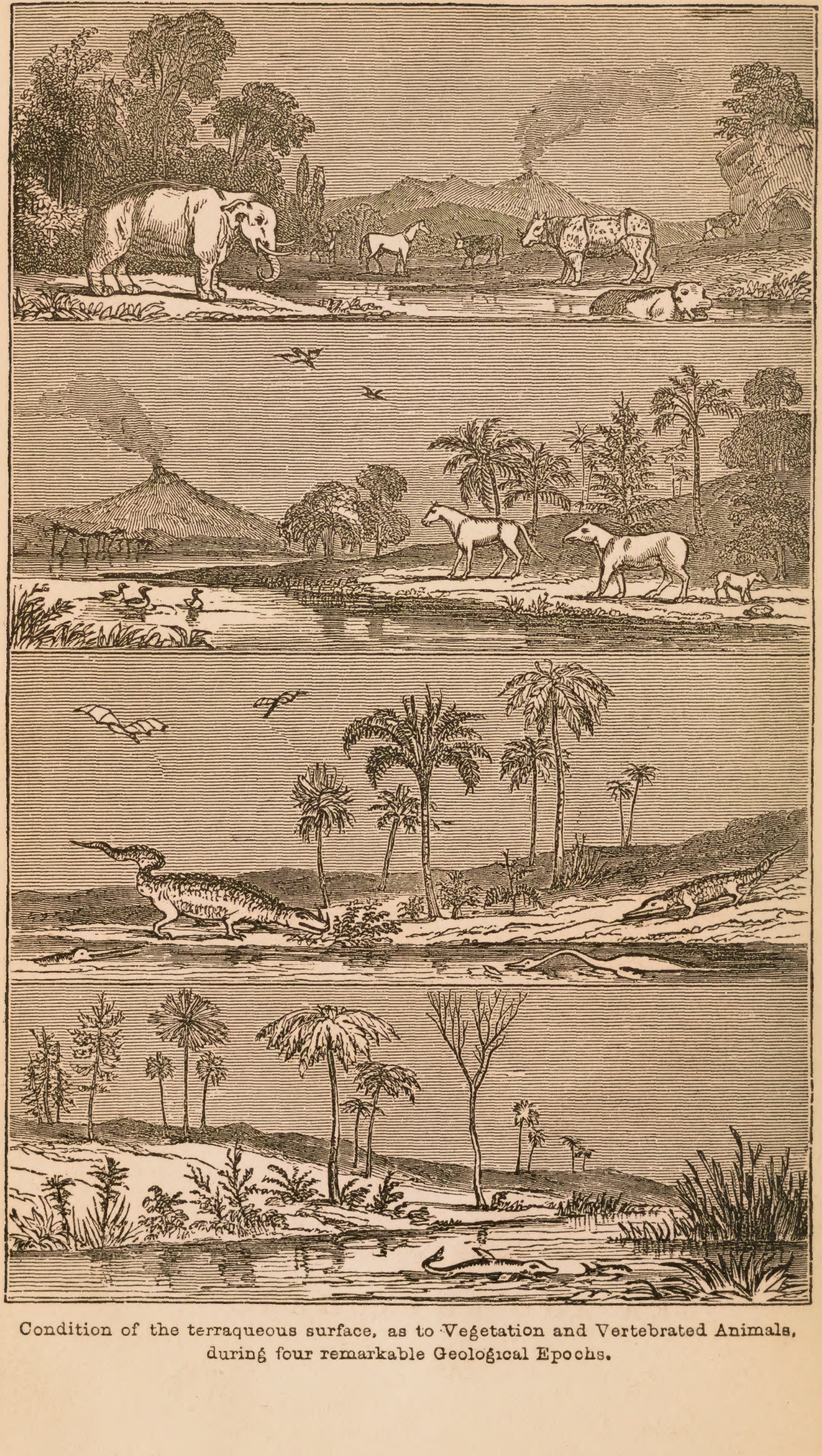
PRACTICAL
GEOLOGY AND MINERALOGY.



Condition of the terraqueous surface, as to Vegetation and Vertebrated Animals, during four remarkable Geological Epochs.

PRACTICAL

GEOLOGY AND MINERALOGY;

WITH INSTRUCTIONS FOR

THE QUALITATIVE

ANALYSIS OF MINERALS.

BY

JOSHUA TRIMMER, F.G.S.

— ITUM EST IN VISCERA TERRÆ.

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PREFACE.

This work was undertaken, and had in part appeared in the pages of a periodical publication, when there was rather a dearth of elementary treatises on geology, and before so many had been sent forth by some of the first geologists of the age, that to add to their number may perhaps appear superfluous, if not presumptuous. Its extension and publication, in a separate form, has been determined on, because it is hoped that it differs sufficiently in its plan from any of its predecessors, to render it a humble but useful auxiliary to works which it does not aspire to supersede.

It has been said that a man may be too consummate a mineralogist to make a good geologist, or, in other words, that the constant study of minute details, necessary for the discrimination of individual minerals, unfits the mind for the apprehension of the sublime generalizations of geology; but, on the other hand, it is no less true, that a certain amount of mineralogical knowledge is an essential requisite to the successful study of that science. It is usual for the authors of elementary geological books to assume that their readers possess this knowledge, or to refer them for it to arranged cabinets and oral instructors, and there can be no doubt that they who have such advantages within their reach will find in them the readiest means of acquiring information; but what are those readers to do—and they are numerous—to whom they are inaccessible? Residing in remote parts of the country, and surrounded by interesting phenomena, they have heard rumours of some of the wonders of geology, and are anxious to examine for themselves the truth of facts on which have been founded inferences so much opposed to received opinions respecting the relative antiquity of the earth and the human race. They purchase some of the best elemen-

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tary books, and read therein of substances perhaps daily before their eyes, but which they are unable to recognise, as names only are given them, and there is no one at hand capable of pointing them out. The consequence is, that, meeting with these difficulties in the very outset of their career, they either abandon the pursuit as hopeless, or, if they do not sit down to write a refutation of geology, rush at once into its obscurest regions, and are discussing the amount of carbonic acid contained in the atmosphere when the coal strata were deposited, or inventing causes by which a change of climate may have been produced, while they cannot distinguish quartz from felspar, are ignorant whether their house is built of sandstone or syenite, and whether it stands upon grauwacke or the lias. Students so circumstanced must repair to the cabinets of the great museum of Nature: in the rocks around them, or in the transported gravel, they will find specimens of almost all the simple minerals, and their combinations, which it is essential for them to know; they must be their own instructors,—the blowpipe and chemical tests their chief resource,—and they may be assured, that with such aids—*experto credite*—moderate perseverance will enable them to surmount all the difficulties which beset the commencement of their path.

It is for the use of such students that the chemical and mineralogical details, which may appear dry and uninteresting to those who read merely for amusement, have been collected from various sources.

In the purely geological part of the work, it has been the writer's aim to confine himself to facts and classifications, and those limited inferences which have received the assent of all geologists, keeping out of sight, as much as the nature of the subject will permit, questions affecting the higher generalizations which are still, and must long continue, matters of controversy. This, however, is not always possible, so insensible is the gradation by which descriptive geology passes into geological dynamics. In one instance, wherein this course has been deviated from, the deviation has been intentional, because the existence—which some deny—of an erratic block period at the close of the tertiary era, is a point of considerable importance in a detail of facts and classifications, and because its establishment will settle one of the most important questions on which geologists are at present divided; for if, in our progress from the known to the unknown, from the present state of nature to the past, we meet at the very first step with a deposit which it is clear must be due to forces of greater intensity than those now in action, there is an end to the assertion of the uniformity of the existing course of nature through all periods of the earth's physical history; and the establishment of such a fact will be tantamount to a decision in favour of those who ascribe the whole series of geological phenomena to long periods of ordinary aqueous and igneous action, interrupted by occasional paroxysms of extraordinary energy.

Another reason why this part of the subject has been treated at greater length than may seem consistent with the professed plan of the work is, that the recent researches and discussions connected with diluvial phenomena constitute one of the few departments of original investigation in which the writer of these pages can claim a share.

A few words are necessary on two subjects, to which some space has been devoted in the early part of the volume, but which in similar works are in general passed over without notice, or only slightly glanced at.

He who, engaged in the active business of life, seeks his recreation in the study of this fascinating science, must be prepared to encounter the censure and the ridicule of two opposite classes; those who deem the pursuit of riches, and those who deem the pursuit of pleasure, the great end of man's being. The one will accuse him of wasting every moment not employed in the acquisition of wealth—of wealth which he who has spent his whole life in accumulating it, finds too late that he knows not how to enjoy, because the incessant pursuit of gain has absorbed the whole of his faculties and stinted all mental cultivation: the other class will charge him with misspending time which they would not deem ill applied to sports of the field or games of chance, to bacchanalian revels or party squabbles. To remove these prejudices is the object of the second chapter. They are, however, fast subsiding, while a sense of the practical value of geology and its kindred sciences is daily gaining ground: witness the establishment by the government, of the Museum of Economic Geology —the rapid increase of local museums of natural history, and the strenuous efforts which have been made, hitherto in vain, but which must ere long succeed, to found a School of Mines in Cornwall.

There are others, however, more entitled to respect than the two classes above-mentioned who look on geology with an evil eye. The incontrovertible conclusions from well-established facts respecting the high antiquity of the earth are viewed with opposite feelings by persons of different characters. Some hail with delight the apparent discrepancy between the truths of geology and the Mosaic account of the creation of man; while in others, who hear only of the conclusions and will not examine the facts on which they rest, they excite feelings of disappointment and regret, and of aversion towards the science and its cultivators. It appears the duty of every sincere believer in the truth of Revelation, who attempts the diffusion of geological knowledge, to place this question in its true light. To accomplish this—to deprive the infidel of a specious argument—to wrest from his grasp a weapon which can only be dangerous if we manifest a dread of it or rush incautiously upon it—and at the same time to remove from the minds of others, prejudices which prevail among some of the writer's most intimate and valued friends to such an extent as almost to obscure the charities of life, were the motives which dictated the third chapter. It was written and had appeared in the periodical already alluded to, before the publication of the "Scripture and Geology" of Dr. Pye Smith, or to that work it would have been sufficient to refer.

The collection of the mass of facts and inductions which constitute descriptive geology, necessarily implies compilation, and the labour of this has been rendered comparatively light by those who have preceded me. The "Outlines" of Conybeare, the "Manual" of De la Beche, the "Guide" and the two Treatises of Phillips, together with his "Geology of Yorkshire," the "Elements" and the "Principles" of Lyell, have been consulted, as well as the "Transactions and Proceedings of the Geological Society," in which the fruits of their original researches, with those of Buckland, and Sedgwick, and Murchison, of Fitton, and Greenough, and Mantell, of Scrope, and Daubeny, constitute so vast a portion of the rich stores of inductive geology.

For chemistry and mineralogy recourse has been had to Turner's "Elements of Chemistry," Werner's "External Characters of Minerals," to the "Introduction to Mineralogy" of W.

Phillips, the "Mineralogy" of Mohs, the "Traité de Minéralogie" of Beudant, and Griffin on the "Use of the Blowpipe."

With respect to the wood-cuts with which the work is illustrated, the shells are taken, with a few exceptions, from Sowerby's "Mineral Conchology;" the plants from the "Fossil Flora" of Lindley and Hutton; the crinoidea and corals from the "Petrefactenkunden" of Goldfuss; the crustaceans from the Work of Brongniart and Desmarest, "Sur les Crustaces Fossiles."

It now only remains to bid the young geologist good speed in the career to which he is invited. Napoleon put muskets into the hands of his conscripts and sent them to the field of battle to learn the art of war. I would bid those recruits, which it is the object of these pages to levy for the service of geology, shoulder their hammers and march on to victory. When once they have broken ground and determined for themselves the names of a few minerals, they will feel no inclination to draw back. The Map of the British Isles by Phillips will indicate their geological position, and the formations which may be expected to occur within a few miles east or west of it. Organic remains will soon attract their attention, and they ought as speedily as possible to make themselves acquainted with at least the genera of recent and fossil shells. There was, till lately, a great want of works on this department of science which were not too costly for the majority of students; but this want has been supplied by the "Manual of Conchology" of Sowerby and the "Malacology" of Swainson, in Lardner's Cyclopædia. To these they may add the "Coquilles Caractéristiques des Terrains" of Deshayes. As the science opens upon them, and they begin, as they soon may, to make discoveries of their own, they will find in it a never-failing source of interest and amusement—charms to beguile the deepest solitude and the dullest hour—power "to soothe all sadness but despair."

The American publishers believing that a glossary would add to the usefulness of this systematic introduction to Geology, have caused a full one to be made, and added to this edition—there having been none in the English edition.

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EXPLANATION OF THE FRONTISPIECE.

The frontispiece, for the design of which I have to acknowledge my obligations to Mr. Whichelo, represents the condition of the terraqueous surface, as to vegetation and vertebrated animals, during four remarkable geological epochs. In the lower compartment the land is seen clothed with lepidodendra, sigillariæ, and other plants of a tropical aspect peculiar to the carboniferous era, which are described in the thirteenth chapter. The only contemporaneous vertebrated animals at present known are fishes, all distinguished by the continuation of the vertebral column into the upper lobe of a tail divided into two unequal lobes. Some of them were of great size, exhibiting a higher organization than the majority of the fishes belonging to more recent epochs, and indicating an approach to the saurian structure. (See page 263.) From the prevalence of these large sauroid fishes, this may be called the megalichthian age.

The poikilitic era, during which true saurians first make their appearance, is passed over because of the paucity of its organic remains; and the second compartment from the bottom exhibits the flora and fauna of the oolites.

The vegetation is still impressed with a tropical character, but constitutes a different group, both as to genera and species, from that of the coal strata.

The ichthyosaur and plesiosaur are seen sporting in the waters, crocodiles basking on the shores, the bat-like pterodactyls flitting through the air, and the huge iguanodon feeding on ferns, clathraria, and cycadeæ. This, which may be called the saurian age, terminates in the cretaceous system, of which the lower beds alone contain any of these strange reptiles, whilst the supracretaceous strata afford genuine crocodiles, approaching to existing types. (See Chapter XV.)

The cretaceous era is passed over like the poikilitic because its characteristic fossils are exclusively marine, and the third compartment exhibits the plants and animals of the early tertiary, eocene, or palæotherian age.

The vegetation still indicates a high temperature in the latitudes of London and Paris, by the prevalence of palms intermixed with coniferæ and other exogenous trees, approaching the character of existing species.

Extinct genera of the pachydermatous order of mammals abound; of these the anoplotherium commune, as restored by Cuvier, is seen on the left, and behind him are palæotherium magnum and palæotherium minus; near the latter is a land tortoise; and it appears from recent discoveries that monkeys might have been represented gamboling on the boughs, and boas coiled around the trunks of the trees. Birds, of which some traces occur in older strata (the new red sandstone, the wealden, and the chalk), are now abundant.

The volcano in the distance represents the craters of Auvergne, at present dormant, some of which commenced their action towards the close of this era, and afford the first decided evidence of subaerial eruptions.

The upper compartment exhibits the elephantoid age. In the foreground are seen the elephant, rhinoceros, and hippopotamus (pachydermata of existing genera, but extinct species), which commenced with the miocene or middle tertiaries, and disappeared from Europe at the erratic block period; in the background are placed the stag, ox, and horse, to intimate the extensive developement of those genera during the pliocene era. The hyæna entering his den indicates the increase of carnivora during this period, and the accumulation of mammalian bones in caverns. The forests consist of oak, fir, birch, poplar, and other trees, closely approaching, if not identical with, indigenous European species. The distant volcano represents the greater part of the eruptions of Central France, of the Rhine, Catalonia, and Hungary, which appear to have taken place during the miocene and pliocene epochs.

PRACTICAL

GEOLOGY AND MINERALOGY.

CHAPTER I.

INTRODUCTION.

Geology—connected with all the sciences—yet adapted for popular study.—High antiquity of the earth—it has been inhabited by many successive creations of plants and animals.—Recent origin of Man.—There is no indefinite succession of geological phenomena.—Existing and extinct organic bodies constitute one great chain of being, the work of one and the same contriving Intelligence.

Sir John Herschell has said of Geology, or the science of the earth, that in the magnitude and sublimity of the objects of which it treats, it ranks in the scale of the sciences, next to Astronomy; to which we may add, that it will ever be more generally cultivated, because a knowledge of it is more easily attainable. It may be successfully pursued without that severe preparatory discipline of mathematical study which is required of the votaries of astronomy, before they can advance even to the threshold of her temple. In making this assertion, it is by no means intended to deny the dependence of geology on the other sciences; on the contrary, it is admitted that he who would be a perfectly accomplished geologist, ought to be familiar with the whole circle of them. He ought to be thoroughly versed in mathematics and general physics, in order that he may know what are, and what are not sound data on which to found his inferences—he ought to be skilled in mineralogy, that he may know the proximate constituents of rocks. Of the general results of chemistry he must not be ignorant, and he will find it a great advantage to be expert in chemical analysis. The organic remains entombed in the strata, will make constant demands upon him for a knowledge of zoology in all its branches, and in particular he ought to possess such an intimate acquaintance with those nice distinctions which constitute specific differences in conchology, as of itself requires the study of a whole life, and such a profound knowledge of comparative osteology, as enabled Cuvier, from the examination of detached bones, to remodel the entire skeletons of animals of unknown genera; such is the harmony of proportion, the adaptation of means to ends, and of parts to uses, which the wisdom of the Creator has manifested in the structure of organic bodies. The geologist ought moreover to be a botanist of the highest order, and in the most extensive sense of the term. He ought to be able not merely to refer a plant to its place in some artificial system, by counting its stamina,—a process which he will rarely, if ever, have an opportunity of applying to the fossil vegetation of former worlds,—he ought to be able, from the examination of a stem, a leaf, or a seed-vessel, to determine the natural group to which the plant belongs, and by pointing out its habits, to throw light on the circumstances under which the stratum containing it was deposited. He ought, moreover, to be a good draughtsman, and a skilful practical surveyor.

Acquirements so varied and extensive as these are attainable by few, and yet much may be done in geology with a very limited proficiency in these branches of knowledge. Without a very profound acquaintance with any of them, we may master all the facts of the science, and all the inferences deducible from them, and what is more, we may be qualified to institute active original research, and to enroll our names on the list of those who have added, by their discoveries to the sum of human knowledge,—for geology is a science of observation,—it is, moreover, a young and advancing science, many of whose data remain to be collected, and in the collection of them there are few who cannot assist. When we know about a dozen of the most common, simple minerals,—when we can recognise their combinations in rocks,—when we know the technical terms of the science, and can distinguish crystalline from sedimentary, stratified from unstratified rocks, — and when we know the order in which the strata composing the earth's crust succeed each other, we are qualified to examine nature for ourselves, and to study geology, where it is best studied, in the field. We require not the expensive observatory or laboratory of the astronomer or the chemist,—all we want is a good hammer, and a strong arm to use it; active legs, a quick eye, and sufficient common sense to enable us to reason upon what we see. For the rest we may trust to the assistance of our fellow-labourers, and to that community of feeling by which they are ever animated; for geology is eminently a social science, and the great and rapid advances which it has made within the last few years, are in a great measure to be attributed to that division of labour, and mutual co-operation which can only be effected by numbers acting in concert.

"These volumes," says Mr. Murchison, speaking of the *Transactions of the Geological Society of London*, "must ever be valuable, as the true records of our scientific progress; but great as may have been the acquirements of their authors, few indeed are the memoirs which have been completed without the aid of other distinguished fellows of the society, who, each in the branch of natural knowledge for which he stands pre-eminent, comes to the assistance of his wandering associate, and enables him to clothe his memoir in an appropriate dress. For where is the working geologist who, unassisted, can unravel the delicate and obscure complications of fossil organic structure? Do his fossil shells require to be identified, has he not the assistance of a Sowerby? and if these types of a former state of nature call for a comparison with existing species, is not a Broderip ever prompt in affording him the result of experienced discernment, and in unfolding the riches of his unrivalled cabinets? If he meet with difficulties in the determination of Mammalia, are not a Mantell and a Clifft at hand, to explain their relations, and define their characters? Or if bewildered in the obscurity of fossil vegetation, is he not assisted by a Lindley? Have not, in fine, a Turner, a Prout, a Faraday, and a Herschell been willing instruments in enabling him to explain those laws of chemical change, without which the recondite parts of the science might have remained in utter darkness? Surely every contributor to our *Transactions* will acknowledge with gratitude the aid he may have received from several of our most gifted members, who, unambitious of personal fame, have been contented with the delightful consciousness of being sure, though silent, instruments in urging on the advance of truth. It is this kindly principle of co-operation, this true latent heat of the Geological Society, so ready to manifest itself on every occasion fitted to call it forth, which, warming and vivifying our endeavours, gives to our proceedings their consistency and their strength, and enabling us to grapple with our hundred-headed science, constitutes the mainspring of our prosperity."*

If geology yields to astronomy in the sublimity of the objects of which it treats, and in being unable at present to bring its truths within the pale of mathematical demonstration, it possesses this advantage, as a science for popular study,—that it presents them to us in a more palpable shape. One of the first, and hardest lessons which we have to learn of the astronomer, is to discard impressions founded on what we deem the evidence of our senses. Misled by these, we have been accustomed to consider the earth as at rest, and the sun as making a daily circuit round it. The astronomer demonstrates the contrary of this, and corrects our notions as to the relative size of the celestial bodies. He determines the figure of the earth, and the form of the orbit in which it moves, and ascertains the velocity of its daily and annual motion. He determines the magnitude of the sun, and its distance from us, and shows us other planets revolving round it, with their attendant satellites, and obeying the same laws which regulate the motions of that which we inhabit. He pushes his discoveries to the utmost verge of the visible creation; and, by the aid of powerful optical instruments, resolves those twinkling points, which we call the fixed stars, into groups of suns moving round each other in "mystic dance;" and he demonstrates that those laws of gravitation, which regulate the fall of bodies on the earth, are universal laws, which are obeyed in the remotest system of worlds within the reach of mortal ken. He can not only calculate the motions of the bodies composing the planetary system, and point out their relative positions for any period of past or future time, but he can predict, within a few hours, the return of those mysterious wanderers, whose course extends into the regions of space, far beyond the remotest planet of our system, and whose periodic times are measured, not by days, but by years.

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* Murchison's Anniversary Address—Proceedings of the Geological Society.

It may be well said that in all this there is an overwhelming sublimity. The distances treated of are so immense, and the time required to complete some of the celestial cycles so vast, that they elude the grasp of our comprehension;—we may talk about billions and trillions of miles, and myriads of years, but we have scarcely a less vague conception of them, than we have of infinity of space and eternity of time. Geology, on the contrary appeals directly to our senses. She lays open the ground on which we tread, and convinces us, that the vast secular periods of the astronomer, which, with him, are mere abstract arithmetical truths, which he cannot prove to have had an actual existence, may all have been required for the production of those changes on the surface of our globe of which we witness the monuments. She proves that our present continents, with the most elevated of their mountains, were formed at the bottom of the ocean; and that our hardest rocks were once sand, and gravel, and mud derived from the wearing down of land no longer in existence. She points to a bed of rock, a few feet in thickness, teeming with the remains of organic life; and, from the successive generations of individuals which it contains, and from other indications, into which we will not at present enter, proves that a very long period must have been required for its formation. She then conducts us through a vast series of similar submarine deposits five or six miles in depth (how exposed to our view will be explained hereafter) abounding with the remains of plants and animals, and containing, not only the relics of successive generations of individuals, but of successively created races, each group of strata having its peculiar group of organic remains. She unfolds, page after page of this great book, this wondrous record of the changes our earth has undergone, and of tribes of beings by which it has been peopled during a series of periods of long but unknown duration, before it was inhabited by man. She first leads us to those formations now in progress in which he and his works are imbedded, together with the remains of the contemporary species of plants and animals.

This page of the world's history is soon read, and man is found to be but a creature of yesterday, compared with the globe he inhabits, and with the other beings with which it has been peopled. The very species of plants and animals now existing are found to have been called into being before him, for their remains occur in older, that is in deeper strata. The remains of existing species are gradually intermixed with those of species that have vanished from the face of the earth. The proportion of extinct species increases as we descend. We come to lower beds still, in which not only extinct species occur, but extinct genera. The forms of organic life recede more and more from existing types, and they diminish in number in the lower rocks, till, at last, we lose all traces of them entirely. During our progress through this vast series of rocks, evidently of submarine formation, we meet with others bursting through them, which are as clearly of igneous origin, and derived from below. The lowest rocks we meet with are of this igneous character, and contain no organic remains. It may be that we have reached the records of a period when the world was unfit for the support of animal and vegetable life. It may be that the earlier pages of its history have been torn out, and that the rocks in question once contained the remains of still older races, but that all traces of them have been obliterated, by the fusion to which the rocks have been exposed. At all events, we have reached the dark ages of the earth's history, and we close the book.

With speculations on the creation of the world,—on the mode in which it was reduced from a chaotic state,—and of the causes which gave to it its present figure, we have nothing to do. They were favourite themes with the geologists of former days, whose wild reveries threw a discredit on the science, from which it was long in recovering, even after its votaries began to walk in a more sober path. The cosmogonists, as they are called, applied themselves to the invention of modes in which worlds might be created, with an industry which, if applied to the observation of phenomena in the world around them, might have led to important knowledge. But that was too humble a task for them. They preferred the field of imagination, and all their labours in that field tended but to bring chaos back again. In contemplating their worlds, it would seem as if "nature's journeymen had made them," and had " not made them well." And yet they arrogated to themselves a command over all the powers of nature, and they were not sparing in their use of them. They made the globe solid or hollow,—they filled it with water, or matter in a state of fusion, as it suited their purpose,—they changed its axis of rotation at pleasure,—and when they were in difficulties they called in the aid of a comet, sometimes to produce a deluge, sometimes a conflagration.

But the day for this mode of philosophizing passed away, and geology, for the last half-century, has been a science of observation and induction, not of invention. Geologists now wisely limit themselves to an investigation of the *crust* of the earth; and vast as a series of deposits five or six miles in thickness may appear to us, the proportion it bears to the diameter of the earth is only as 1 to 1600. The paper covering a globe sixteen inches in diameter, is nearly thick enough to represent it. The series of rocks containing organic remains is found to rest upon rocks which are destitute of them, and which bear evident marks of having been in a state of fusion. The lowest rocks we meet with are of this igneous character. We know that lower still subterranean fires are in full activity, giving rise to volcanos and earthquakes, and, from the great areas over which the shocks of the latter are simultaneously felt, it is probable that the source of internal fire is deeply seated. The mean density of the earth has been ascertained to be twice as great as that of the rocks at the surface; and supposing the interior to be composed of materials equally compressible with those of which the crust consists, the pressure to which the central parts are subject would cause the mean density to be much higher than it is found to be. A large portion of the interior must, therefore, be occupied by cavities, —or must consist of less compressible materials than the rocks of the surface,—or there must be some expansive force within, capable of counteracting the effect of pressure. Central fire may be this counteracting force. This is all we know of the interior of the earth, and perhaps all we ever shall know.

Astronomers have declared, that they can discover, in the planetary system, no evidence of a period when it differed materially from its present state. They do not deny that it had a beginning, but they tell us that they can discover no traces of that beginning, neither can they see any prospect of an end. He who made it can doubtless destroy it, but its destruction will arise from causes unknown to us. It contains not within itself, as far as our observations extend, the seeds of its own dissolution; for it has been demonstrated that all the perturbations which can be produced in the orbits of the planets by their mutual attractions are periodical, and range within certain limits, slowly increasing during the long lapse of ages; then, as slowly diminishing, and never deviating widely from a mean state. The machine, therefore, having been created and set in motion, and having been so constructed as to be capable of continuing its action through all eternity, may have been left to itself, without the further active interference of its Divine Author.

The researches of geology lead to different conclusions. We find that our planet has been subject to great and repeated changes; that there have been changes in the condition of the earth, accompanied by corresponding changes in organic bodies, adapting them to those altered conditions. It is true, that in his investigation of the crust of the globe, the geologist is as little able as the astronomer to perceive evidence of the beginning of things. It is even doubtful whether he is able to carry back his researches to the commencement of organic life; though the paucity of remains in the earlier fossiliferous strata appears to favour the conclusion, that the still older stratified rocks, which contain no organic remains, were deposited when the ocean was destitute of living beings. It is, however, certain that we repeatedly see the commencement of new races, and are obliged, again and again, to have recourse to a supreme Intelligence and a creative Power.

If we examine the marine remains of the strata, we find that whole genera of shells, which in the present seas are most abundant in species, were not in existence till after the chalk was deposited. Other genera again originated about the middle of the series, and soon became extinct, being represented by no species in the tertiary strata, that is, the strata above the chalk. These new creations supplied the place of other races which perished; for some genera are peculiar to the lower groups of rocks, not a single species of them occurring higher in the series than the coal-measures. There are a few, and but a few, genera which, commencing in the lowest fossiliferous strata, have endured through all the changes to which the earth has been subject, and have species existing in the present seas. The changes which occurred in the organization of fishes appear to have been greater, and more rapid, and exhibit a wider difference between those found above and below the chalk, than is observable in the case of molluscs.

The same proofs of organic changes are afforded by the study of fossil botany. The formations containing vegetable remains may be arranged, according to Professor Henslow, in four groups, representing epochs, during any one of which no very marked difference is observable in the general character of the vegetation; but between any two of these groups the change is striking and decided, most of the genera being different, and none of the species alike. The character of the fossil vegetation of the earlier epochs is also such as to warrant the conclusion, that the plants of that epoch grew under a climate both hotter and moister than that of any part of the earth at present; and, since even in Arctic regions, the fossil plants are analogous to those now growing under the tropics, it seems probable that light, as well as heat, was formerly more equably diffused.*

We can scarcely be said, at present, to have sufficient data for determining what were the animals inhabiting the land while the earlier strata were being deposited at the bottom of the sea. It was at one time supposed that a gradual developement of organic life might be traced through the series of formations from inferior to higher tribes, from beings the most simple to those of the most complex structure. It was thought, for instance, that the lower strata contained only the remains of animals without a vertebral column, such as molluscs and crustaceans. Of the former, the oyster and the whelk may be adduced as familiar examples; of the latter, the lobster and the shrimp. It was supposed that marine vertebrated animals did not exist till after the coal-formation was deposited; nor oviparous reptiles, such as lizards and turtles, till a somewhat later epoch; and that warm-blooded animals and birds were not created till after the chalk was deposited. But these views have been greatly modified by recent discoveries. The inference as to the non-existence of fishes, resting, as it did, upon negative evidence, has been entirely subverted. It is now ascertained that their remains occur in strata of all ages, each group of strata being characterized, according to M. Agassiz, by peculiarities in the structure of its fishes: and though the remains of reptiles have not yet been found so low as the coal-formation they have been traced down to the magnesian limestone, immediately above it; which gives to them a higher antiquity than till lately they were supposed to possess. Again, with respect to the remains of warm-blooded animals, five jaws, belonging to at least two species of a small animal resembling the didelphys, or opossum, and about the size of a mole, have been found in the calcareous slate of Stonesfield, in Oxfordshire, a stratum considerably below the chalk. One fact of this kind is of more value than a host of negative evidence, and it is triumphantly appealed to by those geologists who contend for the uniformity of the course of nature from the earliest epochs to the present time. It is evident, they say, that some of our oldest rocks have been derived from the waste of pre-existing land; and, as that land appears to have been clothed with its appropriate vegetation, we have no right to suppose that it was destitute of its appropriate animals. A great ocean like the Pacific, interspersed, like it, with small islands, appears to have prevailed, during the formation of the older strata, over that part of the Northern hemisphere in which are situated those countries whose geology has been most explored. Small oceanic islands do not, at the present day, contain many mammalia, while they are wholly destitute of the larger kinds; and the discovery of such remains, in an oceanic sediment, after its conversion into dry land, must be an event of very rare occurrence, for however abundant mammalia might be on some distant continent, by the rivers of which their carcases would be drifted down, yet before they could be floated out far to sea, they would be almost certain to be devoured by the carnivorous monsters of the deep; and even supposing them to escape this fate, the chances are very much against the discovery of the spot where these rare remains are concealed after the bed of the ocean shall be laid dry.

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* Henslow, in Lardner's Cyclopædia, Botany.

Allowing to this argument its due weight, we must observe, that there are certain tribes of mammalia (as the whale and the seal) which are peculiar to the sea; and the imbedding of their remains in the sediment of a great ocean would be no uncommon event. Yet no traces of them have hitherto been found in the strata below the chalk.* The absence therefore of the remains of marine, as well as of terrestrial, mammalia, appears favourable to the conclusion, that this order of animals was not created until an epoch comparatively recent, though that epoch is proved, by the Didelphoid remains of Stonesfield, to have been more remote than we formerly supposed. We must likewise observe that there is a local deposit, older than the chalk, but more recent than the Stonesfield slate, principally confined to the Weald of Kent and Sussex, and thence named the Wealden, which, from its assemblage of fossils, (derived, with few exceptions, from land and fresh water,) appears to have been deposited at the mouth of a river; and, from the extent of the formation, that river must have drained some large continent. Here, then, we ought to find the remains of mammalia if that class of animals were as abundant in the world then as they were at a subsequent period. But though this deposit has long been under the examination of an eminent geologist, celebrated for his skill in comparative anatomy, not a trace of such remains has yet been discovered. On the contrary, the Wealden exhibits a most curious group of animals as inhabiting the shores and waters of the river which drifted down their remains, and indicates an extraordinary developement, during that era, of the saurian, or lizard family. They seem to have possessed earth, and sea, and air. Inhabiting the sea, there was the ichthyosaurus, a creature intermediate between a crocodile and a fish,—having the snout of a dolphin, the head and teeth of a crocodile, the doubly concave vertebræ of a fish, fitting it for rapid motion through the water, and, instead of fins or feet, it had four paddles, like those of a whale; while nearly allied to it in structure was the plesiosaurus, one species of which had a long neck like the body of a serpent. These creatures appear, from their structure, to have been confined to the sea, and never to have appeared on dry land; but there were amphibious saurians, of the crocodile and alligator families, frequenting the rivers and estuaries in company with tortoises and turtles; and there were pterodactyles, or flying saurians, together with a great variety of gigantic terrestrial saurians, the lord of whom appears to have been the iguanodon, a creature pronounced by Cuvier to be the most extraordinary that had ever come under his consideration. It was an herbivorous lizard, of colossal proportions, for it must have been seventy feet long, and nine feet high. In some respects its teeth bore an analogy to those of the iguana, a small species now inhabiting the West Indies; but it differed from all other herbivorous lizards, either fossil or recent, in having chewed its food, as appears by the manner in which its teeth were worn, whereas other herbivorous lizards nip or crop theirs, and swallow it without mastication. In short, during the Wealden era, there were lizards twice the size of the largest elephant or rhinoceros, approaching them in the character of their dentition, and apparently occupying their place in the economy of nature.

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* The bones found in the Wealden, and described by Dr. Buckland, as belonging to Cetacea, are referred by Cuvier and Mantell to some unknown Saurian.

But whether mammalia existed during the earliest epochs of the world of which we possess geological monuments, and were contemporary with those marine animals imbedded in the lower strata, though, for the reasons above stated, their remains have not yet been discovered; or whether they were not created till a later period, though still before the deposition of the chalk, it is certain that during the tertiary era, when their remains were abundantly entombed in the strata, we can trace the introduction of new races even of them. The remains of the land quadrupeds, imbedded in the older tertiary strata, are exclusively those of extinct *genera.* In the deposits of a more recent period we meet, in these northern latitudes, with the remains of extinct *species* of genera now existing, but existing only in warm climates, such as the elephant, rhinoceros, hippopotamus, &c. These are found to be gradually intermixed (in the ascending order of the strata) with the bones of mammalia, identical in species with those now living under the present climates of Europe; till at length we come to peat bogs, and alluvial deposits, in which human remains occur, mixed with those of animals now living in the countries where the remains are found, together with a few which are become locally extinct, within the historic period. The animals that have become locally extinct in Britain are, the wolf, the beaver, and the wild boar. The great fossil elk of Ireland, now universally extinct, perhaps continued to exist in that country after it was inhabited by man. It is almost certain that the elephants, hyænas, tigers, &c., whose remains are so abundant in gravel and in caves, did not inhabit Europe after the human era. In those cases where their bones occur in caverns, mixed with the bones and works of men, there is often evidence that the latter were introduced after the former; and in no case is there clear evidence that they were deposited simultaneously. It is needless to adduce proofs of the recent introduction of man upon the earth. It is a fact admitted by all geologists, even by those who contend that the existing order of things is but the last link of a chain of events derived from laws now in daily operation. The most able and strenuous advocate of this doctrine asserts, that the real difficulty consists in tracing back the signs of man's existence upon the earth to that comparatively modern period when species, his contemporaries, began to predominate.

The absence of human remains from the older strata cannot be accounted for, as in the case of the quadrupeds of the land, by the rare occurrence of the circumstances which would cause them to be buried in submarine sediment. "No inhabitant of the land," says Mr. Lyell, "exposes himself to so many dangers on the waters as man, whether in a civilized or a savage state; and there is no animal, therefore, whose skeleton is so liable to become imbedded in lacustrine and submarine deposits: nor can it be said that his remains are more perishable than those of other animals; for in ancient fields of battle, as Cuvier has observed, the bones of men have suffered as little decomposition as the bones of horses, which were buried in the same grave. But even if the more solid parts of our species had disappeared, the impression of their form would have remained engraven on the rocks, as have the traces of the tenderest leaves of plants, and the soft integuments of many animals. Works of art, moreover, composed of the most indestructible materials, would have outlasted almost all the organic remains of sedimentary rocks. Edifices, and even entire cities, have, within the times of history, been buried under volcanic ejections, submerged beneath the sea, or ingulfed by earthquakes; and had these catastrophes been repeated through an indefinite lapse of ages, the high antiquity of man would have been inscribed in far more legible characters on the framework of the globe, than are the forms of the ancient vegetation, which once covered the islands of the Northern ocean, or of the gigantic reptiles which, at still later periods, peopled the seas of the Northern hemisphere."*

It can scarcely, we think, be denied, that the facts above enumerated point to something very like a progressive developement of organic life; though they will not support the doctrine to the extent contended for a few years ago, and though the terms in which it was announced, might be open to objection. It is possible to repudiate the monstrous and absurd notion of Lamarck, respecting the transmutation of one species into another,—it is possible to admit that fishes, reptiles, and mammalia occur respectively in older strata than was supposed at the time Sir Humphry Davy wrote his *Consolations in Travel*,—we may admit the absence from the coal strata of fungi, lichens, and mosses, which are the simplest forms of flowerless vegetation, and the presence of ferns and Lycopodiaceæ, which are the most highly organized of the cryptogamic† plants,—we may admit that the monocotyledons‡ of the same period consisted of the most highly developed of that class of plants, and that it was not destitute of its dicotyledons.§ It may be true that an orthoceratite or a nautilus, though they have no back-bone, are, for the purposes for which they were designed, as perfect in their organization as an elephant or a crocodile; and that palms and bread-corn, though they have but one seed-lobe, are not inferior in dignity to an oak and a nettle, which have two: and yet, admitting all this, we may contend with Professor Sedgwick, that a doctrine may be abused, and yet contain much of the elements of truth,—that it is one thing to refute it, and another to point out the errors and overcharged statements of its supporters.

"With reference," he says, "to the functions of the individual, one organic structure is as perfect as another; but I think that in the repeated, and almost entire, changes of organic types in the successive formations of the earth,—in the absence of mammalia in the older, and their rare occurrence (and then in forms entirely unknown to us) in the newer secondary groups,—in the diffusion of warm-blooded quadrupeds, (frequently of unknown genera) through the older tertiary systems,—in their abundance (and frequently of known genera) in the upper portion of the same series,—and, lastly, in the recent appearance of man on the surface of the earth, now universally admitted,—in one word, from all these facts combined we have a series of proofs, the most emphatic and convincing, that the existing order of Nature is not the last of an uninterrupted succession of mere physical events, derived from causes now in daily operation, but on the contrary, that the approach to the present system has been gradual, and that there has been a progressive developement of organic structure, subservient to the purposes of life."*

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* Lyell's Prin. of Geol., i. 241.

† Plants whose fructification is concealed.

‡ Plants having only one seed-lobe.

§ Plants having two seed-lobes.

While these changes were taking place in the organic world, changes as great were taking place in the inorganic. Land was converted into sea, and sea into land, and land again into sea. The same portions of the earth's surface have been subject to repeated oscillations, so as to be alternately above and below the ocean level. We have already alluded to the indications of a change of climate, discoverable in the crust of the globe. We shall not at present enter into a detail of all the evidence on which this rests; suffice it to say, that from the testimony of organic remains, it appears that, during the formation of the older strata, a tropical, if not an ultra-tropical, climate prevailed over the Northern hemisphere, and that even at a period so comparatively recent as the commencement of the tertiary series, a very high temperature existed over what are now the cool regions of Europe; when a great part of England was yet beneath the waves, when her mountain-chains formed a cluster of spice-islands, haunted by the crocodile and the turtle, and when, on the spot where London now stands, the nautilus of the tropics, spreading his sail to the breeze, was the only representative of the fleets that crowd her port. But if the earth's crust furnishes us with evidence, that great and repeated changes have taken place in the organic and inorganic world, it furnishes us with proofs, no less clear, that great epochs of time elapsed while these changes were in progress, —epochs so great that we are tempted to connect them with the seuclar periods of astronomy to which we have before alluded.

There is, however, this difference between the phenomena of astronomy and geology; that in the former we have a series of events recurring in a fixed order, after the lapse of fixed intervals of time, whereas in geology (if we except the interchange between land and sea, and the recurrence of volcanic action after long intervals of repose) we have no evidence of the repetition of a single phenomenon, much less have we evidence of geological cycles, in which the same events are repeated, again and again, in a stated order, and at stated intervals. We have proofs of a change from a hot to a colder climate; but we have no proofs of a change from a cold climate to a hotter. Whole orders of fishes characteristic of the older strata become extinct, and are succeeded by new races, which in their turn give place to others. This class of vertebrated animals affords an unbroken record, from the earliest to the most recent geological epoch, and the changes which occur in it are more rapid than those which take place among invertebrate animals; but, as we ascend in the series of strata, we meet with no instance of the revival of any of the extinct genera or species. By means of a series of geological monuments, we can trace the commencement and decay of the family of the Ichthyosauri; but once extinct they reäppear no more, except in the humorous sketch of Mr. De la Beche:* and lastly, man becomes an inhabitant of the earth, but there is not a particle of evidence that the race had previously existed, though at some very remote period, and had been destroyed to revive on the completion of a great geological cycle. Again, to use the language of Professor Sedgwick, "each formation of geology may have required a very long period for its complete developement: but, after all, the successive formations about which we speculate, however complex in their subdivisions, are few in number; and after deciphering a series of monuments, we reach the dark ages of our history, when having no longer any characters to guide us, we may indulge at will in the creations of our fancy. We may imagine indefinite cycles, and an indefinite succession of phenomena, and in the physical world as well as in the moral, we may have our long periods of fabulous history. But these things belong not to inductive geology; and all I now contend for is, that in the well-established facts brought to light by our investigations, there is no such thing as an indefinite succession of phenomena."†

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* Sedgwick's Anniversary Address—Proceedings of Geological Society.

When the Copernican system of astronomy was established, and the earth, no longer regarded as the centre of the universe, was proved to be one of a system of bodies revolving round the sun, the question naturally arose, were the other bodies of that system habitable and inhabited; and, reasoning from analogy, astronomers were disposed to answer the question in the affirmative. It was true, that as regards the distribution of light and heat, and the intensity of gravitation, a very different state of things must prevail in most of those planets from that which obtains on the earth; but seeing that every part of this earth was crowded with sentient beings, possessing an organization so adapted to the conditions of existence assigned them, as to render that existence a state of enjoyment, it appeared highly improbable that all the variety here displayed should be limited to one planet, and that all the others should be mere blanks, made only to be gazed at by us, and destitute of beings suited to their respective states. And when the modern researches of astronomy extended to the fixed stars, showed them to be suns, like that which forms the centre of our system, and when it was found that they were arranged in groups, circling round each other, the argument from analogy was carried further, and the probability was inferred of each of these suns being attended by its system of planets, with their satellites, the whole teeming with life under a countless variety of forms, and under a countless variety of conditions. Geology comes in aid of these conjectures, by showing that this our planet has existed under a different distribution of land and sea, of heat, and perhaps of light, from that which it at present enjoys; and that, under these different circumstances, it was not a mere blank, but was as much crowded as now with living beings adapted to the then state of things. A contemplation of the variety of organization manifested in the world around us, cannot fail to excite our wonder; but if we extend our researches to the remains entombed in the earth's crust, our wonder is increased at the increased variety we find; and we are convinced that the existing system of nature is but a part of what has been, and that the whole visible creation, past and present, may be but an atom compared with the invisible.

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* Allusion is here made to a lithographic sketch from the pencil of that gentleman, entitled "Reappearance of Ichthyosauri—man only found in a fossil state;" in which Professor Ichthyosaurus is represented lecturing to an audience of his brethren, on a human skull, which he pronounces to belong to one of the inferior animals on account of the insignificance of the teeth, and the trifling powers of the jaw, expressing wonder how the creature procured its food.

† Anniversary Address—Proceedings of Geological Society.

If we apply ourselves to the task of classifying organized bodies now existing, arranging them in groups as they differ from or resemble each other in their structure, we find that those forms of each group which are most dissimilar, are connected by a series of gradations, separated from each other by the most minute distinctions, and that the groups, whether we regard the larger or the subordinate divisions, are again connected by forms possessing some of the characteristics of two groups. There are, however, cases in which the transitions are more abrupt; and when these cases occur we frequently recover, among the extinct forms of an ancient state of nature, those connecting links which are wanting in the existing creation. As instances, we may mention the ichthyosauri, before alluded to, as combining some of the characters of a lizard with those of a fish, and occupying among saurians the place of the whale and seal among mammalia. We may mention likewise pterodactyles, which bore the same analogy to lizards that the bat now bears to mammalia. The pachydermatous* order of mammalia, as existing at present, consists of but few genera,—the elephant, rhinoceros, the hippopotamus, horse, hog, and tapir, genera possessing but slight resemblance to each other, and singularly poor in species. The tertiary strata of the Paris basin abound, however, in remains of extinct animals, of this order, supplying gradations between some of the above genera, and connecting it with other orders. There are above forty fossil species belonging to one division of it which contains only four living species. Similar instances might be adduced from other divisions of the animal kingdom; and others are afforded by a comparison of fossil and recent vegetation.

Thus existing and extinct organic bodies can scarcely be said to belong to different systems, but must be considered as composing one great chain of being, formed on one general plan, agreeing, for the most part, in important points of structure, and differing only in minutiæ of detail. And if, on examining the organization of beings whose functions we understand, we discover a mechanism like the work of our own hands, but far surpassing in beauty, in excellence, and complexity any workmanship of man; and if in this we see proofs of contrivance, of structure designed for an end, and that end accomplished, we not only discover among fossil organic bodies new and unexpected instances of this, but we have proofs that the same contriving Intelligence has been exerted at the remotest period to which we can trace back the history of the globe, ages, we know not how long, before the existence of the human race.

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* Thick-skinned.

We find, moreover, that with every change in the state of the earth there has been a corresponding change of organized bodies, and thus we have proofs, not only of an Intelligence adapting mechanism to an end, but of successive manifestations of the same contriving Intelligence, adjusting the mechanism to the altered conditions under which it was to exist. With what reverential ideas ought these views to impress us respecting that Being to whom all things owe their existence, eternal in duration, absolute in power, perfect in wisdom, in goodness infinite; and how can we refrain from exclaiming, in the language of Holy Writ, "O Lord, how manifold are thy works, in wisdom hast thou made them all: the earth is full of Thy riches: they shall perish, but Thou shalt endure; yea, all of them shall wax old as doth a garment, and as a vesture shalt Thou change them, and they shall be changed, but Thou art the same and thy years have no end."

We have now pointed out some of the leading facts which geology presents to us, and some of the lofty speculations to which they lead, and we have compared them with those of astronomy. Before we proceed to the details of the science, we shall offer a few observations on the advantages attending the study, and we shall endeavour to remove those scruples which cause many well-meaning persons to view it with an unfavourable eye, as opposed to facts recorded in the Sacred writings.

CHAPTER II.

Practical application of geology—to mining—to agriculture.—Soils.—Mineral manures.—Draining.—Artesian wells.—Selection of road materials, and of lines of road—of building materials.—Utility of the study of geology as an exercise for mind and body—as a relaxation to the man of business—and as occupation for the unemployed.

But what is the use of geology? This is a question which we have often heard asked, and to which the querists generally reply in the same breath, by denouncing it as a visionary speculation, or, at the best, laborious idleness, productive of no practical results. On this point we are prepared to join issue with these objectors, and to vindicate the utility of our science.

In enumerating the advantages to be derived from it, we shall begin with its economical importance, because the majority of mankind is composed of those who refer all things to this standard. And here we must confess that, as regards utility, as well as the loftiness of their speculations, geologists must be contented to yield the first place to astronomy. We pretend not to guide the sailor across the deep, and to enable him, by measuring the distance of the moon from some of the fixed stars, to ascertain, within five miles, his situation on the pathless ocean, after he has been months without seeing land; but, upon our own element, the land, we can confer upon mankind benefits of no mean order. We can assist the farmer to fertilize the surface of the earth, so that two blades of grass shall grow where one grew before; and we can impart system to the labours of the miner, so that, no longer groping his way in the dark, or trusting to dreams, to omens, and the divining-rod, he may prosecute, with confidence, and with an approach to certainty, those costly operations which are necessary, in order to extract from the earth the treasures there stored up for our use. These treasures exist in sufficient abundance to afford a rich reward to our toils, and at the same time they have wisely and beneficently been rendered sufficiently difficult of access, to stimulate industry and call forth all our energies.

The mineral wealth of the earth has not been distributed through it at random; but each formation, as geologists call a group of strata, is, over extensive areas at least, the peculiar receptacle of certain minerals. Thus, tin is found only in granitic districts, and copper is most abundant in those and the adjoining schistose rocks. That thick formation of limestone, to which the name of Carboniferous has been given, because the great body of the coal-measures rest upon it, is, in England, the chief depository of lead. These metals, with silver, and some others, occur in veins, traversing the strata. Gold, on the contrary, is rarely met with in veins, but is disseminated in small quantities through the rocks in which it occurs, and the principal supplies of it are derived from alluvial gravel, which has resulted from the destruction of those rocks. Platinum and diamonds are likewise found in alluvial gravel. Iron, to which the name of precious might with more propriety be applied than to gold or silver, occurs in the greatest abundance interstratified with coal; so that, by an admirable arrangement of Providence, the bulky ore of this useful metal is found in juxtaposition with the fuel and the limestone necessary for its reduction to the metallic state.

In the present state of our knowledge, it is too much to affirm that these general rules prevail over the whole earth; but they hold good over extensive portions of the earth's surface, though, even within those areas, there are exceptions to the rule; and the study of the rule and the exception is alike profitable.

Let us take, for example, the case of coal. Though raised from great depths below the surface, coal is vegetable matter, accumulated during the earlier ages of the world; so that we are warming our houses, and lighting our streets, and spinning our cotton, and propelling our steam vessels, and are shot along a railway at the rate of sixty miles an hour, by means of fuel derived from the wreck of forests that flourished myriads, perhaps, of years before the existence of the human race.

Deposits of vegetable matter occur in formations of all ages, but they occur in general only in thin seams, and in small quantities. The great coal-deposit lies between two systems of rocks, known by the names of the old and the new red sandstones, closely resembling each other in mineral composition, though very different in their zoological characters. A few years ago we should have said that the carboniferous limestone was the base of the coal-measures; but Professor Sedgwick has shown that in the range of this formation towards the north of England, it becomes a complex deposit, containing beds of shale and sandstone, with seams of coal, which on the borders of Scotland are so largely developed, as to be worked for the supply of the metropolis. It may, therefore, be said, that the great mass of bituminous coal, capable of being profitably worked, lies above the old and below the new red sandstone. The coal-fields of Brora, in Scotland, and of Whitby, in Yorkshire, can scarcely be called exceptions, though they are situated in a newer group of rocks, called the oolitic. For they afford an inferior kind of non-bituminous coal, worked only to supply a local demand.

In communicating these facts, we are obliged to anticipate the knowledge of our readers as to the order in which the strata succeed each other,—

> Things by their names we call, though yet unnamed,—

and therefore, perhaps, they can scarcely perceive the full import of these remarks. In that case, we must request them to return to the subject when they shall have become familiar with the names of the formations, and with their order of superposition.

Now, the practical results to be derived from a knowledge of this general rule and its exceptions are these: that searches for coal ought only to be undertaken with the greatest caution, and under peculiar circumstances, in strata beyond the limits of the regular coal-formation; but that in certain situations, where dislocations of the strata have brought to the surface portions of these anomalous coal-measures, and when the carbonaceous matter is seen *in force*, the working of them may sometimes be attended with success, in districts which are ill supplied with coal from the coal-measures, properly so called. The same remark applies to the lignite, or wood-coal, of the tertiary strata, which is wood partially carbonized, affording a very inferior fuel, which would never be used where the produce of the coal-fields of Newcastle, or Staffordshire, or South Wales, could be easily obtained. In England, which is so abundantly supplied with coal of the best description, lignite occurs but sparingly, but on the Continent it is sometimes largely developed, and extensively worked.

Copper is not generally met with in strata more recent than the old red sandstone; but there are in England some exceptions to this rule:—the celebrated Ecton mine, in Staffordshire, and the Llandidno, or Orme's Head mine in Caernarvonshire, being situated in the carboniferous limestone. On the Continent, the ore of this metal is worked in a formation even still more recent, the copper-slate of Thuringia being a portion of the new red sandstone series. The advantages to be derived by the practical miner from a knowledge of these facts are obvious. On the one hand, the general rule will prevent a waste of capital in fruitless searches for certain minerals in strata where they rarely occur, and on the other hand, the exceptions will prevent that slavish adherence to the general rule which would prohibit all attempts to work them in those strata, when the indications are in other respects favourable; and geology furnishes us with means for discriminating the different strata, and teaches us their order of succession; so that having ascertained to what part of the series a given rock belongs, we know what other rocks we may expect to find above and below it.

Mineral veins, again, are not equally productive through all parts of their course, but masses, or "bunches," as they are called, of ore, are locally distributed through the vein, being connected by thin strings of ore, or by barren portions of the vein-stone, which are only useful as guiding the miner to the richer deposits. His object, therefore, is to arrive at the productive portions of the vein, with the expenditure of the least possible labour, on barren ground; and this object he attains by observing the circumstances under which these bunches occur in those particular veins on which he is employed, till, by repeated observations, he discovers the laws which they follow, and knows those parts of a vein which are likely to be most productive. But these laws are not the same in all mineral districts. If, therefore, we remove from any of our most celebrated mining-counties, one of its most experienced practical miners, and if we place him in another, where different laws prevail, for the distribution of ore in veins, and where, though minerals may be abundant, those laws are not yet known by experience, because no mines have yet been worked; all his practical knowledge acquired from observations in his native district will avail him nothing, perhaps will become absolutely injurious, because it will be likely to prevent his paying attention to the suggestions of those who have studied mineral veins on a more general scale. This study forms one department of geology, and the mine-agent, who possesses most knowledge of it, is most likely to conduct mining operations with success. A person of this kind is too often branded by the ignorant with the epithet, "theoretical," whereas, he is in fact, the really practical man, because he concentrates and combines in himself the knowledge derived from the observations of all practical miners in every part of the world.

We cannot quit this subject, without expressing astonishment that Great Britain, which owes much of its greatness to its mineral riches, and where so much property is embarked in mining speculations, should have been so long without establishments like the *Ecoles des Mines* of the Continent, in which superintendents of mines and working miners might be instructed, at a trifling expense, in the rudiments of geology, mineralogy, chemistry, and other branches of science immediately connected with their occupation. It is to be hoped that the British Association for the Advancement of Science will turn their attention to this subject, for nothing will tend so much to the advancement of science as the union of practical and scientific knowledge in the same individuals. In the depths of the mine, which philosophers only visit occasionally, phenomena of the utmost importance for the elucidation of those hidden laws of nature which they are investigating, are daily passing unnoticed before the eyes of working miners. When they shall have become imbued with such a portion of scientific knowledge as will be useful to them in their vocation, and with that love and respect for science which this knowledge will engender, these phenomena will arrest their attention, and though they may not themselves be capable of generalizing from them, they will not fail to bring them under the notice of those who have the ability to do so.*

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* The Mining Record Office and Museum of Economic Geology, established by the Government, and placed under the direction of Mr. De la Beche, since this passage was written, promise to be of the utmost practical utility. The former originated in the recommendation of the British Association, and will be the means of preventing much waste of capital, and of preserving many valuable lives in the coal districts. From the want of plans of the old workings, it not unfrequently happens that shafts are sunk at a heavy expense, in quest of a seam of coal, which when

The benefits which geology can confer on agriculture are neither few nor trifling. Our limits will not permit us to point out in detail how the nature of a soil depends on that of the rocks from the disintegration of which it was derived, nor to show how particular plants affect particular soils, in which, in a state of nature, they exclusively flourish, and in which they flourish most in a state of cultivation, so that by consulting a good geological map, of a given district, we may predict before we enter it, the species of crops which will be found most extensively cultivated there, and which experience has proved to be best adapted to it.

A due mixture of earths in a soil is essential to its fertility. The most productive districts of England have been made so by nature, and owe their fertility to this mixture; and it is by copying nature that we must proceed in our endeavours to improve those that are barren. Neither pure clay, sand, nor chalk, afford productive soils. Those are the best which contain a mixture of the three earths, silica, alumina, and lime, with a portion of decomposed animal and vegetable matter. These are the soils so much coveted by the farmer, which will bear repeated cropping without manure. The principal ends proposed in agricultural improvement are, to render wet soils dry and dry soils sufficiently moist, to render adhesive soils loose and loose soils sufficiently adhesive; and the proportion in which the earths above mentioned should be mixed for these ends must depend upon the climate and the substratum. Aluminous, or clayey soils, retain too much moisture, and siliceous, or sandy soils, part with it too rapidly; and a soil, good in itself, may be rendered unproductive, by resting on too retentive or too porous a substratum. Draining, or irrigation, is in such cases the remedy. When one of the earths prevails in a soil to the exclusion of the others, great improvement may be effected by the addition of that which is deficient, and it is astonishing, as Mr. De la Beche has remarked, that the superior fertility observable along the line of junction of two rocks, occasioned by the mixture of their component parts, has not oftener induced agriculturalists to have recourse to various artificial mixtures of the materials of rocks which are adjacent to each other, either as regards the surface, or depth below the surface. There are districts in which such mixtures have been practised with the greatest success; but in general, farmers rely too exclusively on farm-yard manure. Clay, sand, and limestone, are, nevertheless, mineral manures of the greatest value, and have changed the face of whole districts that were before comparatively barren. By such mixtures, the constitution of the soil has been improved,—causing the animal and vegetable manure afterwards applied to be more efficacious.

The clayey lands of Essex have been greatly improved by the use of chalk. This acts upon the land in several ways. It de-

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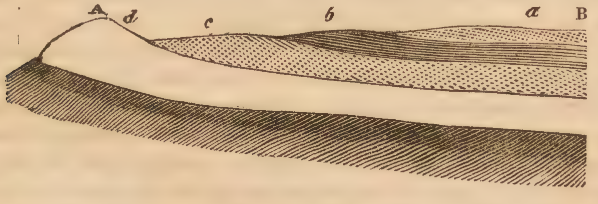
reached proves to have been long worked out. Lamentable accidents also happen from the carrying on of operations too near to accumulations of water in abandoned workings, the proximity of which was not suspected.

composes any free acids, and some acids in combination, naturally existing in the soil, and which are prejudicial to vegetation, and it acts mechanically, by rendering the soil more pervious to moisture, and affording greater facilities for the roots of plants to expand. When chalk is not at hand, a dressing of sand or fine gravel will produce some of these results, particularly if it contain calcareous matter, in the shape of fragments of limestone or broken shells. Clay, again, is equally efficacious on sandy soils, by increasing the power of the soil to retain moisture, and by enabling the roots to maintain themselves firmly in the ground.

In Norfolk and Suffolk, vast tracts of land, which were before incapable of bearing corn, have, by the application of clay, been made to produce good crops of wheat, barley, clover, and turnips. Thus, a greater number of cattle are kept upon a given area, and the quantity of animal and vegetable matter returned to the soil is proportionably increased. The mineral manures are, in general, too much neglected, with the exception of lime, (the injudicious use of which too often runs into the abuse,) and even in those districts where they are applied, they are frequently brought from a distance, when, though not visible on the surface, they exist at a small depth below it, sometimes under the very field for the improvement of which they are required. Now, who, we would ask, is most likely to discover them,—he who never looks deeper into the earth than the bottom of his ditches, or he who studies the position of rocks with respect to each other, and for this purpose examines every natural section by which they are exposed to view in cliffs and ravines, and every artificial section laid open by mines, wells, and other excavations?

Fig. 1.



Let A B in the annexed diagram (fig. 1) represent the surface of a district composed, like some of the eastern parts of England, of strata of sand, clay, and gravel, resting upon chalk, all the strata having a slight inclination to the eastward, or towards B: a farmer cultivating the sandy soil at *a*, knows, for he observes it in riding to market, that at a certain distance from his own farm, he shall cross a tract of clay, *b*, and that after leaving that, he shall meet with sand and gravel again at *c*, and that at *d* he shall quit the plain and reach hills of chalk. But he does not know, and he would probably laugh at the person who communicated the information, that all the strata *b*, *c*, and *d*, are to be found under his own land at *a*, at a depth proportioned to the thickness and inclination of the strata, so that a bed which, in one part of an estate will be at a considerable depth, may rise in another very near the surface. But these are points to the determination of which the geologist applies himself, and having ascertained, from the nature of the imbedded fossils, that the stratum *a* is the crag, and *b* the London clay,—he knows that by proceeding in a direction contrary to that in which the strata dip, he shall meet with the sands and gravels of the plastic clay, as well as with the chalk rising successively to the surface.

A knowledge of the stratification of a country will also sometimes prove valuable to those engaged in agricultural improvements, by enabling them to drain their land more effectually, and at less expense, than by the ordinary methods. A good soil, as was before observed, may be rendered unproductive, by resting on a bed of clay, which holds up the water, and there may be a porous bed again beneath the clay. Now, if the thickness of the clay is not too great, such land may be freed from excessive moisture by perforating the bed of clay, and leading the surface-water into the perforations.

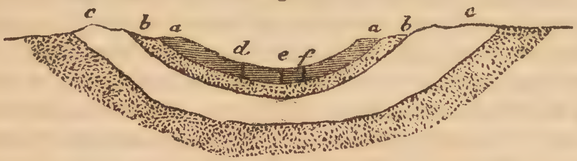
The dip or inclination, and also the "faults" or dislocations of the strata of the district, ought to be studied with the same view. These faults are fissures which traverse the strata, and produce two opposite effects with respect to drainage, according to the nature of the substances with which they are filled. Sometimes they are pervious to water, and then they act as natural main drains, into which subordinate drains may be turned. In other cases, they are filled with clay, and then they act as natural dams, holding up the water in the strata to a higher level on one side of the fault than on the other. A fault so filled is often traceable on the surface by the land-springs which break out along its course, arising from the pent-up water struggling to escape wherever there is the least resistance; and cases will occur, in which, by piercing through the fault, vent may be given to the water which before burst out at several smaller openings, and the land may thus be laid dry at a cheaper rate than by contending with each spring individually. This water, which was injurious in one place, will sometimes be in sufficient quantity, when thus collected into one channel, to improve another part of the estate, by being employed in irrigation, or by being made to drive an overshot wheel. Artesian wells have been bored to obtain a supply of water for both these purposes.

The nature of a country is sometimes such that it is destitute of rivers and surface-springs, and then the population are dependent for a supply of water upon that which can be obtained by means of very deep wells, or upon that which falls from the atmosphere, and is collected in ponds or tanks. The water derived from the former source is obtained at a great expense; that derived from the latter is by no means wholesome, and is liable to fail in dry summers. In such seasons we have seen the population of an extensive parish almost fighting for the green unwholesome water of a muddy pond; and cases have occurred, in which it has been necessary to drive the cattle so far to drink, that by the time they returned they were as thirsty as when they started. Few greater benefits could be conferred on a district so circumstanced, than the establishment in it of Artesian wells.

These derive their name from the district of Artois, in France, where they are supposed, though it appears erroneously, to have been first used. Artesian wells are nothing more than perforations a few inches in diameter, made through the strata with the ordinary boring-tools, and their action arises from the natural tendency of water to find its level.

It is only under certain conditions of geological structure that they can succeed: and the structure of the district in which it is proposed to introduce them ought to be thoroughly investigated before any borings are attempted, because, though one of these wells may be made for one-third of the cost of an ordinary well of the same depth, yet it will be perfectly useless, though a water-bearing stratum should be penetrated, if the water will not rise to the surface, the orifice being too small to admit of its being raised by mechanical means. If a reservoir of water were formed on the side of a hill, and a leaden or other closed pipe were laid from it to a hill on the opposite side of the valley, the water might be conducted in this pipe to the same height as that of the source, and wherever a hole were made in the pipe, the water would gush out and endeavour to attain the level of that at the two ends. The geological structure answering to these conditions is shown in the annexed diagram (fig. 2), which represents the stratification of the vale of London. *a a* is a retentive stratum at the surface (in this case the London clay); *b b* a bed of gravel and sand below it, both of them resting upon the chalk, *c c*; and the whole series having been thrown, by some subterranean movement, into a curve, concave on the upper side. This, in geological language, is the basin-shaped structure. The porous bed, *b b*, fulfils the office of the closed pipe before mentioned. The water which falls on the chalk-hills, *c c*, is absorbed by this porous bed, and prevented from escaping by the bed of clay above, and by the chalk below it, and if the clay be pierced by small borings as at *d*, *e*, and *f*, will rise to the surface, or to heights above the surface, proportioned to the elevation of the source, and to the obstacles which the water meets with in percolating through the bed, *b b*. There are other modifications of this structure which need not be noticed in a brief sketch like this.

Fig. 2.



There are few persons conversant with rural affairs, who are not aware how much good roads improve the value of property by facilitating the conveyance of the produce of the land to a market, and either for the improvement of old, or the formation of new roads, a knowledge of the strata over which they are formed is of the utmost importance. The durability of a road depends in a great measure upon the materials employed, and upon the solidity of its foundation. These points are, in general, too much neglected by those to whom the formation of roads is intrusted, the chief objects of attention being the shortening of distance, and the reduction of acclivity; and to obtain these, a road is often carried over strata affording an unstable base, and liable to frequent land-slips. Soft and bad stone is also frequently employed, because it is near at hand, when better materials might be brought from a distance by means of canals and railways, at a small extra expense, which would be in the end more economical, because of their greater durability, and because when used they afford a good instead of a bad road. On the other hand, stone of inferior quality is often brought from a distance of several miles, when better exists much nearer; not quarried, it is true, nor visible on the surface, but easily discoverable by the eye of the geologist. Hardness is not the only essential in a stone employed for the repair of roads. It is required not only to resist friction, but also the crushing force of heavy carriages, moving with considerable velocity, Hence a certain degree of toughness is necessary to durability. Yet when hard and tough materials are both at hand, the latter is often neglected for the former.

There are situations in which flints from the chalk, and chert from the green sand, might be obtained for the roads at the same cost. The chert, as the toughest, is the best: yet surveyors of roads, looking only to hardness, or perhaps merely adhering to established custom, almost invariably prefer the flints. Masses of greenstone, again, are of frequent occurrence in the midst of granitic districts. Granite is reduced to powder under the crushing action of wheels much sooner than greenstone, owing to the superior toughness of the latter, which arises from the presence of the mineral called hornblende. This mineral enters largely into the composition of most of the trappean rocks, a numerous family, which, though differing much in external aspects, all possess, in a greater or less degree, the toughness essential to a good material for roads. We will illustrate this subject by one or two examples.

The improvement which has taken place of late in the roads in the neighbourhood of London, must be well known to most of our readers. Much of this has been effected by reducing the surface to a better form, and by applying the materials used in a more judicious manner; but much has arisen from the selection of better materials.

Under the old system, these consisted exclusively of gravel raised in the neighbourhood, much mixed with sand and clay, from which it was difficult effectually to clear it. In mineral composition, it consisted chiefly of flint, but the pebbles being for the most part round could never form so solid a mass as a layer of angular pieces of stone. The first improvement was to substitute for this gravel broken flints from Kent, brought up the river Thames. Possessing hardness only, without toughness, their brittleness was found to be an objection against them, and granite was substituted. This was found more durable than flint, but less so than a rock containing hornblende from Mount Soar Hill, in Leicestershire, which is now chiefly employed, and with manifest advantage.

The surface of the counties of Lancashire and Cheshire is occupied chiefly by the new red sandstone formation, which affords no road materials, but stone of the most friable kind. The roads of this extensive district are now supplied with a trap-rock from Penmaen Mawr on the coast of Caernarvonshire, and the quantity used is so great, that even at the low price at which it is supplied, the persons who have taken a lease of these rocks are realizing large profits. Stone of the same kind occurs in many parts of the Snowdonian chain, but nowhere so near the sea, except in Caernarvon Bay; and even the small additional freight which must be paid for its conveyance thence, is sufficient to prevent it from competing successfully with the stone of Penmaen Mawr. Whoever, therefore, shall succeed in discovering within the district thus supplied, a mass of trappean rock, so situated as to be easily quarried, may be assured that he has made a valuable discovery. Mr. Murchison has shown that in a part of Shropshire trappean rocks have burst through the new red sandstone, and it is by no means improbable that the action may have been prolonged into Cheshire. It sometimes happens that only a small portion of trappean rock rises to the day, when there is a large mass at a small depth below the surface; and the surface-appearances are also such as to deceive a person in search of road materials, who was unpractised in geological investigations; for some of the hardest and toughest of these rocks decompose by long exposure to the atmosphere, presenting the appearance of an incoherent bed of earth, on removing which, the unweathered rock will be found to afford a stone well adapted to the repair of roads.

Attention to the direction in which the strata dip will frequently save considerable expense, both in the first construction and future maintenance of a road, when it is carried along the side of a hill through a stratified country.

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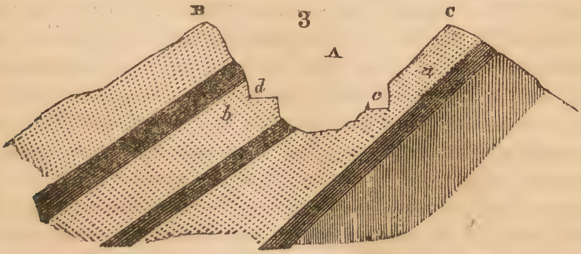

Let A (fig. 3) represent a valley between the hills B and C, composed of many alternations of shale and sandstone, having a steep dip; so that had the beds of B not been denuded, they would have covered those of the hill c. Let *a* and *b*, moreover, be two beds of loose sandstone, on opposite sides of the valley, with beds of clay or shale beneath them. If a road be cut at *c*, the water percolating through the sandstone, and prevented from descending by the retentive bed below, will have a constant tendency to throw down upon the road portions of the rock above; but no such effect will be produced if the road be cut at nearly the same height on the opposite side of the valley, at *d*, where the strata dip *into* the hill instead of *out of* it.

Every architect and civil-engineer ought to be a geologist, for the study of the structure of rocks, and of the situations in which they occur, would frequently enable them to select more durable stones for building than those usually employed. These remarks apply to public works rather than to private edifices, for under the present system the houses in most of our great towns are built by speculators who have no permanent interest in them, and they are built for profit, on a calculation, nicely adjusted to the length of a lease, which they are not intended to outlast. But when a proprietor builds upon his own estate, he ought not, from motives of injudicious economy, to use stone liable to rapid decomposition, merely because it can be worked at less cost than another which is more durable; and above all, when a nation builds, which builds for posterity, all such paltry parsimony ought to be discarded. Yet some of the finest of the public buildings in London, less than two centuries old, are hastening rapidly to decay, from having been constructed of a calcareous sandstone, soft when first raised, and thence easily worked, hardening as it loses its original moisture, but liable again to imbibe water, and therefore easily affected by frosts.

An improvement in this respect has lately taken place in the substitution of granite for sandstone in many of our public works: but the indiscriminate use of this material may be attended with bad effects; for some varieties of granite, like the trappean rocks before alluded to, though hard and difficult to work, when first raised, afford a bad building material, from the rapidity with which they decompose. This depends on the state of the felspar they contain. Rocks, in which the felspar exists in a compact state, are in general more durable than those in which it is found in coarse crystals. Some sandstones, again, which have a siliceous cement, are very durable. The weathered surface of a rock will often give a better insight into its mineral structure than can be obtained from a fresh fracture, for which reason, the geologist, in selecting hand specimens, endeavours to procure one such surface; and in general the capability of a stone to resist atmospheric agency may be learned by studying the manner in which it resists such action in its original situation, and by observing which of the ingredients of a compound rock is the first to decompose.*

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* The late Dr. William Smith, when asked how he judged of the relative durability of different kinds of stone, replied, "I go into the churchyards. The dates are on all the tombstones." The commissioners appointed to ascertain the best stone

We have now taken a rapid glance at some of the practical advantages resulting from the study of geology. The subject is by no means exhausted, but our limits will not allow of further details. It remains to speak of other benefits arising from the cultivation of the science, less direct, it is true, and to some minds less obvious, but not the less important, because they cannot be made to enter into a calculation of pecuniary profit. As an employment for the mind, and an exercise of the reasoning powers, geology may be placed in the first rank, second only to the exact sciences, and in some respects superior to them, because it requires the exercise of those faculties, and employs that kind of reasoning, for which we have daily need in the conduct of human affairs. The practical application of the mathematics is limited to a few professions. That is not the object with which they are studied by one in a hundred of those who devote so much time to them. They are studied in order to strengthen the mind by accustoming it to habits of attention and investigation, and even when cultivated with this view, doubts have been entertained whether they may not be pursued too exclusively. It has been asserted, that the mind may become so habituated to that strict demonstration which the abstract sciences require and afford, as to reject other truths incapable of the same kind of proof. And yet on most of the questions on which we are called upon to form a judgment as to matters-of-fact, past, present, and to come, mathematical reasoning is inapplicable, and we must be satisfied to arrive at a moral certainty to be attained by weighing evidence and balancing probabilities. This is the highest degree of proof of which most geological inquiries are susceptible, and this is the mode in which they are conducted. We observe the changes taking place around us in the organic and inorganic world; we trace effects up to their causes, and then comparing like things with like, we infer that similar effects were produced by similar causes in the ages that are past. In this investigation we have often to weigh the conflicting evidence of apparently irreconcilable phenomena; we are perpetually seeking analogies, or detecting differences, or combining and generalizing scattered facts with which observation has furnished us. Occasionally, too, we find ourselves obliged to retrace our steps, compelled by new facts to abandon generalizations, founded on imperfect induction. Surely all this must tend to produce habits of acute observation, patient investigation, and salutary caution, in suspending our judgment in the absence of complete and satisfactory evidence, habits of the greatest value in the affairs of life, and we must be most unapt scholars if we do not at the same time learn this great moral lesson—that it is pos-

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for the construction of the new Houses of Parliament, after examining most of our ancient edifices, have decided in favour of the crystalline varieties of the magnesian limestone, which are those, as Professor Daniell has shown, in which the magnesian compounds approach the nearest to equivalent proportions of carbonate of lime and carbonate of magnesia.

sible to acknowledge ourselves to have been in error, without either compromise of dignity or loss of strength.

Geology possesses this advantage over most other sciences, that with discipline for the mind it combines exercise for the body. It has power to preserve or to restore the "mens sana in corpore sano." One at least of our most celebrated geologists applied himself to this pursuit, as a remedy for disorders, brought on by too close an application to sedentary studies. Health appears to be a privilege almost peculiar to the geologist, among all the sons of science. The mathematician undermines his constitution over his diagrams and his equations—the chemist inhales poison, amidst the fumes of the labratory—the anatomist risks his life, amidst the horrors of the dissecting-room,—but the geologist enjoys the robust health of the sportsman, or the peasant. He breathes the purest air of heaven, amidst the loveliest and the sublimest scenery of nature, whilst exploring those mountain recesses, where her mysteries are best revealed; hardy, active, and enterprising, he ranges through all the realms of Europe—now on the summit of Ben Nevis—now in the caves of Staffa—now among the wilds of Connemara—and now in the valley of the Arno. He has examined the extinct craters of the Rhine, and the crater of Etna, still in full activity; his hammer has been heard among the pine-forests of Norway, and he has looked down from the Alps, and cried with the poet—

> Creation's heir—the world, the world is mine!

He sees mankind under various forms of government and religion. He holds intercourse with men, whose sole bond of union with him is their ardour in the cause of science. On all other points their opinions differ, and even on some of the controverted matters of geology they are ranged on opposite sides. Hence, he is trained to habits of moderation and forbearance, and learns to emancipate himself from the trammels of party.

Those ancient convulsions to which the globe has been subject, and those physical features which they have impressed upon its surface, are not confined within the narrow conventional limits of tribes or nations; to study them, he must have a free and unmolested passage through all the kingdoms of the earth. Hence, those bad passions which array nation against nation, injurious as they are to all, have this additional evil for him, that they retard the progress of his science, which requires for its developement nothing less than the peace of the world. The subjects of his investigations are so various, and the questions to be solved by him are so complicated, and so connected with all the kingdoms of nature, that he is prevented from devoting himself too exclusively to any one branch of study; he finds at every step that he needs the aid of fellow-labourers in other departments of the great field of knowledge. Hence arise new sympathies; and there are many who can enumerate among the advantages of geology, the warm and enduring friendships to which it has given birth. In the roving life of the geologist, there are charms unconnected with those of science: he mingles in his rambles with men of all ranks, and of various characters, and thus gains an opportunity of studying human nature whilst he obtains fresh knowledge of his profession.

The personal adventures of a geologist would form an amusing narrative. He is trudging along, dusty and weaterbeaten, with his wallet at his back, and his hammer on his shoulder, and he is taken for a stone-mason travelling in search of work. In mining-countries, he is supposed to be in quest of mines, and receives many tempting offers of shares in the "Wheal Dream," or the "Golden Venture;"—he has been watched as a smuggler; it is well if he has not been committed as a vagrant, or apprehended as a spy, for he has been refused admittance to an inn, or has been ushered into the room appropriated to ostlers and postilions. When his fame has spread among the more enlightened part of the community of a district which he has been exploring, and inquiries are made of the peasantry as to the habits and pursuits of the great philosopher who has been among them, and with whom they have become familiar, it is found that the importance attached by him to shells and stones, and such like trumpery, is looked upon as a species of derangement, but they speak with delight of his affability, sprightliness, and good-humour. They respect the strength of his arm, and the weight of his hammer, as they point to marks which he inflicted on the rocks, and they recount with wonder his pedestrian performances, and the voracious appetite with which, at the close of a long day's work, he would devour the coarsest food that was set before him.

Geology can only be studied thus by those who are gifted with leisure and affluence, or by those who follow it as a profession; but, on a less extended scale, it is available to the man of business and the man of humble income. The rich and the unemployed will find in it a substitute for those artificial excitements, those frivolous and often vitiating and ruinous pursuits to which they are driven as a resource against *ennui*, and he who is engaged in active labours may resort to it as a relaxation from toil and care. If a state of total inactivity is unsuitable for man, so likewise is a state of unremitting labour. Rest and recreation we all require: change of employment is often equal to repose; and where can we find employment or recreation so refreshing and invigorating, both to mind and body, as this? What can be more delightful than to exchange that conflict of passions and interests, which beset the man of business in his intercouse with men, for that calm, yet exciting interest, arising from converse with nature, and the acquirement or discovery of truth?

Geology has fields of research suited to every labourer, and to every capacity. On some of its investigations, the highest intellectual powers, and the greatest acquirements in abstract science, may be brought to bear, while many of its problems may be solved by any one who has eyes and will make use of them. Extensive travel is requisite to afford comprehensive views of the structure of the earth, and to prevent our generalizing from too limited an induction; but he whose travels are confined within his native country, or within a circle of twenty miles round his own house, may add much to our knowledge. Nor is this class of observers by any means the least useful. He who makes a hasty excursion through a district, can give but a general outline of its structure, leaving many important points of detail to be filled up by resident observers. If we visit the same cliff or the same quarry daily, for years, we shall, at every visit, be rewarded with something new; and there are few districts barren in objects of geological interest, however deficient they may be in the beauties of picturesque scenery.

CHAPTER III.

The discoveries of geology not opposed to revealed religion.—The Bible contains the moral history of man, not a revelation of physical truth—its language with respect to natural phenomena is an accommodation to popular notions and sensible appearances.—A long interval between the creation of the universe and the creation of man not inconsistent with the Sacred narrative.—The Noachian deluge—the marine remains of the stratified rocks once erroneously regarded as proofs of it—the diluvial gravel since referred to the same event on insufficient evidence—not all contemporaneous—no proofs of its formation within the human era.—There is nothing in the history of the flood to warrant the expectation of finding geological monuments of it.

We have now enumerated some of the advantages of geology, and some of the pleasures attending the study of it; and is it to be wondered that a science possessing such attractions, so important in its results, so fertile in new discoveries, and whose lofty and boundless speculations possess an interest almost poetic, should be remarkable for the enthusiasm with which it inspires its votaries, or that their number should daily increase? There are those, however, who, admitting all that can be urged in its favour, would yet dissuade us from the study, as opposed to the highest and best interests of mankind, by tending to undermine our belief in the truth of the Sacred records. To these objectors, whose motives we must respect though we cannot applaud their judgment, we would reply, that their advice appears to argue a lurking distrust of the truth of what they profess to believe; for it amounts to a recommendation that we should close a great and important chapter in the volume of God's works, lest it should be found at variance with the volume of his Word. Conflicting falsehoods there may be; but truth can never be opposed to truth, however they may differ in their principles, and in the means by which we obtain a knowledge of them. We could never have become acquainted with the relations of man to his Creator, and with God's Providence in his dealings with man, which is moral truth, except by means of revelation; neither in the absence of a revelation of physical truth, can we discover those secondary causes, by means of which the material world is governed, except by observation, experiment, and induction; and as long as we adhere honestly to that course we never can arrive at any thing but truth.

The study of the material world is nowhere prohibited, but, on the contrary, has the express sanction of many passages of Scripture. *Great,* says the Psalmist, *are the works of the Lord, sought out of all them that have pleasure therein;* and he never breathes more rapturous devotion, nor rises to loftier strains of poetry, than when expatiating on the beauty and the wonders of creation. It is true there are some natures which convert into poison that which to others is wholesome nutriment, and there are some minds which betray a morbid eagerness to discover in every new fact in physical science an argument against the truth of revelation. But are we to abstain from that which is in itself good because others pervert it to evil? If we, from a laudable, though mistaken zeal, abjure the study of natural science, the infidel and the sceptic will not. They, on the contrary, will pursue it the more eagerly the more likely they think it to afford a position from which revealed religion may be successfully assaulted. Surely, then, the believer, instead of leaving them in possession of the field, ought to consider the study of natural science an imperative duty, that he may be able to foil such assailants with their own weapons; for if he enter the contest, as too many injudicious advocates have entered it, unacquainted with the true nature of the phenomena bearing on the question, and ignorant of the condition of the problem he undertakes to solve, he can only bring discredit on the cause which he attempts to serve. The assailants of revelation usually assume, and too many of its defenders argue on the assumption, that we have reason to expect a system of physical science in the Sacred writings; but the slightest consideration of the purpose for which they were given, must convince us that such a revelation would have been quite at variance with their professed object. That object was to make man acquainted with his relations to his Creator—with his original state—his present condition—his future hopes. Such a communication contained too much that was humiliating to human pride, to obtain a ready acceptance, notwithstanding the high credentials by which it was supported; and to have connected with it a system of physical science, opposed to the prevailing notions respecting the material world, instead of facilitating its reception, would have afforded fresh grounds for incredulity, by the announcement of facts apparently contradicted by the evidence of the senses. Moreover, to have made physical truth the subject of revelation, would have destroyed its great use as an exercise of the reasoning powers; and would have deprived it of its highest interest, by superseding all discovery, and leaving to us only the task of committing to memory that which was plainly recorded.

The object of Natural Religion is to trace the Author of Nature in his works; and with this physical science has an intimate connexion. The object of Revealed Religion is the providential history of man; and with this natural science has only an incidental connexion, arising out of such physical facts as are mentioned in the course of that history.

We have already briefly noticed the manner in which geology confirms and extends the evidences of natural religion. Before we proceed to examine its bearings on the few physical facts recorded in the Inspired writings, let us consider the case of astronomy with respect to those writings. Astronomy may be regarded as a nearly perfect science; and its conclusions rest upon a basis which cannot be shaken—mathematical demonstration, the highest degree of proof of which truth is susceptible. Yet we do not find in the Scriptures the remotest hint by which even a clue might be obtained to those great astronomical truths, which have been slowly and laboriously worked out by the process of observation and induction. On the contrary, every notice of those subjects is such as to favour popular notions, derived from the first sensible appearances of the heavens and the earth. But surely we are not therefore called upon by true religion to reject a system of physical truth, founded on the clearest demonstration, any more than we are required by sound philosophy to disbelieve a revelation of moral truth, supported by its appropriate train of moral evidence and credible testimony. Ought we not rather to consider the manner in which the phenomena of the natural world are spoken of in the Scriptures as a proof that the moral destiny of man is all that has been revealed; that the phenomena and laws of the material world are left to be discovered by human reason; and that, when speaking incidentally on subjects connected with physical science, the language of inspiration has been accommodated to popular notions and sensible appearances, in the same manner that when speaking of his own incomprehensible attributes the Almighty has adopted language suited to human comprehension?

No sane person would now attempt to overthrow the modern system of astronomy by appeals to the text of Scripture. But astronomy was not always in its present matured state. It has been said of our science that it is scarcely yet out of its cradle; and its present state may be compared to that of astronomy when the discoveries of Galileo were deemed hostile to religion. But, after all, the facts hitherto brought to light by the researches of geology, are more in accordance with the text of Scripture than are those of astronomy. What can be gathered from the brief account of the creation contained in the first chapter of Genesis, more than this: that the world was not self-existent and eternal; that it was called into being by the fiat of an Almighty Creator; and that, though He could have produced it in an instant, clothed, as we now behold it, with plants, and furnished with inhabitants, it was his pleasure to proceed gradually in the work of creation; and that man was the last, as he is the noblest, of his Maker's works? And what, we would again ask, is there in the phenomena of geology inconsistent with this? It may be doubtful whether we see the remains of the earliest races of beings by which the waters were inhabited; and there may be a difference of opinion, in the present state of our knowledge, whether there were any animals of the higher orders contemporary, as inhabitants of the land, with those marine races, whose remains we find in the ancient strata, but the recent origin of man, as we have before shown, does not admit of a doubt. On that point all geologists are agreed,—those who believe the sacred records and those who do not; and, as Cuvier has said, we cannot, from geological monuments, date the introduction of the human race upon the earth at a more remote period than about six thousand years ago.

With regard to the time occupied in the gradual work of creation, there have been differences of opinion arising out of the text itself, independent of any geological investigations; and though the majority of commentators have maintained, that by the days of creation are to be understood periods of time equal to that in which the earth performs a revolution on its axis, others have contended that they might be periods of long and definite, though, to us, unknown duration.

But this extension of the term is by no means necessary; for the phenomena of geology may be reconciled with the Mosaic account of the creation by the supposition that, after God had, "in the beginning," created the heavens and the earth, a long, undefined period may have elapsed, during which a series of revolutions may have taken place, which are passed over in silence, as being totally unconnected with the history of the human race; that, at the termination of this period, the earth was in the chaotic state described in the second verse of Genesis; and that, at this point, the narrative of the six days of creation commences; during which the earth was again restored to order, covered with the existing races of plants and animals, and finally made the abode of man.

On either interpretation of the term *day*, whether it be restricted to days of twenty-four hours, or be extended to periods of definite but unknown duration, a difficulty will remain, connected rather with astronomy than with geology. This difficulty is, that according to the received interpretation, the sun was not created till the fourth day. If, therefore, the word day is to be taken in its ordinary acceptation, those days that succeeded the creation of the sun must have been very different from those that preceded that event; and if, by days, we are to understand long periods, then, during three of those long periods, the earth must have existed independent of those laws of gravitation of which the sun is, to our system, the centre, and not only must it so have existed, but during one of those long periods it must have been clothed with vegetation, "herb yielding seed, and fruit-tree bearing fruit," without the aid of solar influence. But this difficulty will be removed by adopting the interpretation suggested by Dr. Buckland, in his *Bridgewater Treatise;* that the sun and moon were not called into existence on the fourth day; that they were then prepared and ordained to certain offices of high importance to mankind, who were shortly to be created. According to this interpretation, the heaven and the earth, declared in the first verse to have been created by God in the beginning, mean the universe, including the sidereal systems, with the planets and their satellites; the earth being specially mentioned, as the subsequent scene of those creative operations which were about to be described. A long, undefined period, to which we have before alluded, between this primitive creation and the present order of things, is supposed to have terminated; and with it to have terminated a long series of geological epochs. This would be the commencement, or evening, of the first day, when the earth lay in confusion and emptiness, the wreck and ruins of a former state, involved in temporary darkness and a temporary state of submergence. The work of the first morning was to dispel the darkness that overspread the ancient earth. On the third day the waters were commanded to be *gathered into one place* and the dry land to *appear;* but neither land nor waters are said to have been created on that day. The same interpretation may be applied to the fourteenth and four following verses; what is there stated respecting the celestial luminaries appearing to be spoken without any regard to their real importance in the universe, but solely with reference to our planet and the human race. Light may have been readmitted to the earth on the first day, the exciting cause of light remaining obscured by mists which hung over the earth, and the further purification of the atmosphere, on the fourth day, may have caused the sun, moon, and stars, to reappear in the firmament, and to assume their new relations to the human race and the reconstructed earth.

The declaration, in this place, that God made them, will then merely be a repetition and amplification of part of the first verse, intended to warn the Israelites against that early and prevalent superstition which led to the worship of the host of heaven. These explanations, by which the letter of the text of Genesis is reconciled with geological phenomena, are supported by Dr. Buckland, by the authority of Hebrew critics, and of several learned and pious divines. He further shows that it had long been a question among theologians, whether the first verse of Genesis ought to be considered, prospectively, as a summary announcement of that creation, the details of which are given in the records of the six successive days, or as an abstract statement, that the universe was created by God, without defining the period when that creation took place; and it is also stated, on the authority of the Regius Professor of Hebrew, at Oxford, that, in some old editions of the English Bible, in which there is no division into verses, there is a break at the end of what is now the second verse; and that, in Luther's Bible, (Wittenberg, 1557,) there is, moreover, the figure 1 placed against the third verse, as being the beginning of the account of the creation of the first day.

Referring those who are desirous of seeing this question more fully discussed, to the interesting volume from which the above abstract is taken, we shall conclude this part of the subject in the words with which Dr. Buckland concludes his chapter on the consistency of geological discoveries with sacred history.

"After all," he says, "it should be recollected that the question is not respecting the correctness of the Mosaic narrative, but of our interpretation of it; and still further it should be borne in mind, that the object of this account was not to state *in what manner*, but by *whom*, the world was made. As the prevailing tendency of men, in those early days, was to worship the most glorious objects of nature, namely, the sun, and moon, and stars, it should seem to have been one important point in the Mosaic account to guard the Israelites against the polytheism and idolatry of the nations around them, by announcing, that all these magnificent celestial bodies were no gods, but the work of one Almighty Creator, to whom, alone, the worship of mankind was due."*

Having thus endeavoured to show, that as regards the recent origin of the human race, the researches of geologists confirm the Sacred narrative; and that the high antiquity which they claim for the globe, on the evidence of a vast series of extinct races of organized bodies, entombed in the earth's crust, is by no means inconsistent with the literal interpretation of that narrative, the only remaining event mentioned in Scripture which can have any connexion with geology is the general deluge.

Phenomena of two opposite kinds have, at different times, been appealed to as evidences of that event,—the organic remains contained in the stratified rocks, and the loose covering of gravel, clay, and sand, distributed over the surface of the earth.

When the study of the structure of the earth first bega to attract the attention of Europe, in the beginning of the sixteenth century, the marine remains discovered gave rise to much discussion; some maintaining that they were not real remains, but mere sports of Nature, formed by what they called a "plastic force," which had power, it was said, to fashion stones into the forms of organic bodies. Others contended that they were the real exuviæ of animals that had lived and died on the spots where their remains occurred; and others again contended that they were left in their present situations by the Noachian deluge, to the transient action of which they atributed the formation of the stratified rocks, in all their vast thickness, with their numerous subdivisions, and with all their successive groups of extinct races.

More than a century was spent in proving the animal origin of these remains, and in refuting the notion of their having been produced by a "fermentive process" or "a plastic virtue," and for more than another century and a half, the discussion was maintained whether they were the remains of animals gradually accumulated at the bottom of the sea, subsequently converted into dry land, or whether they were left by the deluge of the Sacred writings. The latter opinion was not finally abandoned by geologists, till the close of the eighteenth century; when Werner, in Germany, and Smith, in England, had, independent of each other, established the order of succession of the stratified rocks; and Smith had proved that each group of strata is characterized by its peculiar group of organic remains. The researches of Cuvier among the extinct animals of the tertiary formations of the Paris basin, were likewise affording additional proofs of the gradual accumulation of strata, and of the remoteness of the forms of mammalia imbedded in even these comparatively modern rocks, from any forms now living on the face of the earth.

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* Buckland's Bridgewater Treatise, vol. i., p. 33.

About the same time, the notice of observers was attracted to the water-moved gravel, and other phenomena indicating the passage of large bodies of water, at a recent epoch, over a great part, not of Europe only, but of the Northern hemisphere. This gravel is composed chiefly of fragments of the rocks of the neighbourhood in various states of attrition, mixed with others which must have been drifted from a distance, and are now found considerable to the south of the rocks from which they have been derived.

Huge blocks of granite and other rocks, dispersed through and lying upon this gravel, are found in situations far to the south of their parent-rocks; and have frequently been lodged in a most extraordinary manner, high on the flanks of mountains, between which, and the chains from which they were derived, wide and deep valleys intervene. Bones of mammiferous quadrupeds, of existing genera, but of species extinct, or existing at present only in warm climates, are found in this drifted matter, mixed with some that are now inhabitants of Europe; and, within the last few years, fragments of marine shells, of existing species, have been discovered in it, in various parts of Great Britain and Ireland, sometimes at considerable heights.

These evidences of diluvial action were next connected by geologists with the Noachian deluge, and with much greater probability than the stratified rocks which had been referred to that event. This hypothesis, first propounded by De Luc and other observers, was warmly taken up by Dr. Buckland, who gave to this transported gravel the name of diluvium. The new diluvial theory obtained the support and sanction of Cuvier, and soon became popular among geologists. There were some few, however, who ventured to dissent from it even during the height of its popularity, objecting to it that it represented the flood of the Scriptures as an impetuous torrent which had greatly modified the surface of the earth, excavating valleys, transporting immense blocks of rock, and covering hills, as well as valleys, with vast accumulations of debris; whereas it should appear from the brief narrative of that event in Genesis, that the rise and retirement of the waters were gradual, and even that vegetation was not destroyed by them. It was objected, moreover, that in the gravel supposed to have resulted from this deluge, no human remains or works of art had ever been found, but only the remains of animals, a large proportion of which belonged to extinct species. As our knowledge of the tertiary strata extended, it was seen that lacustrine and marine deposits, of gradual accumulation, and belonging to different epochs, had been confounded with this diluvium. There appeared, too, reason for supposing that some of the extinct volcanic cones of central France, and some of the minor cones on the flanks of Etna, were formed at an era more remote than that of the historic deluge, or the human race; and they exhibited no traces of diluvial action, though consisting of loose scoriæ and sand, which could not, for a moment, have resisted the rush of a violent flood. The investigations, moreover, of Elie de Beaumont showed that the mountain-chains of Europe had been elevated at several distinct epochs; and geologists began to connect the superficial gravel with these periods of elevation, supposing that, in some cases, it had been shot off the flanks of the nearest mountains during their elevation, or that the violent agitation into which parts of the ocean had been thrown by the sudden upheaving of its bed, had given rise to great waves which had rushed over the land.

The hypothesis which attributed all the superficial gravel in the world to one event, and that the Noachian deluge was abandoned successively by those who, for a time, had been some of its most zealous supporters. Professor Sedgwick renounced it from the chair of the Geological Society, in the year 1831, in the following words:—

"Bearing upon this difficult question, there is, I think, one great negative conclusion now incontestibly established,—that the vast masses of diluvial gravel scattered almost over the surface of the earth, do not belong to one violent and transitory period. It was, indeed, a most unwarranted conclusion when we assumed the contemporaneity of all the superficial gravel upon the earth. We saw the clearest traces of diluvial action, and we had, in our Sacred histories, the record of a general deluge. On this double testimony, we gave unity to a vast succession of phenomena, not one of which we perfectly comprehended, and under the name of diluvium we classed them all together.

"To seek the light of physical truth, by reasoning of this kind, is, in the language of Bacon, to seek the living among the dead, and will ever end in erroneous induction. Our errors were, however, natural, and of the same kind which led many excellent observers of a former century to refer all the secondary formations of geology to the Noachian deluge. Having been a believer, and to the best of my power, a propagator of what I now regard as a philosophic heresy, and having more than once been quoted for opinions I do not now maintain, I think it right, as one of my last acts before I quit this chair, thus publicly to read my recantation.

"We ought, indeed, to have paused, before we first adopted the diluvial theory, and referred all our old superficial gravel to the action of the Mosaic flood. For of man, and the works of his hands, we have not yet found a single trace among the remnants of a former world entombed in these ancient deposits. In classing together distant unknown formations under one name; in giving them a simultaneous origin; and in determining their date, not by the organic remains we had discovered, but by those we expected hypothetically hereafter to discover in them; we have given one more example of the passion with which the mind fastens upon general conclusions, and of the readiness with which it leaves the consideration of unconnected truths.

"Are, then, the facts of our science opposed to the Sacred records? And do we deny the reality of an historic deluge? I utterly reject such an inference. Moral and physical truth may partake of a common essence, but, as far as we are concerned, their foundations are independent, and have not one common element. And in the narrations of a great fatal catastrophe handed down to us, not in our Sacred books only, but in the traditions of all nations, there is not a word to justify us in looking to any mere physical monuments as the intelligible records of that event: such monuments, at least, have not yet been found, and it is not, perhaps, intended that they ever should be found. If, however, we should hereafter discover the skeletons of ancient tribes, and the works of ancient art, buried in the superficial detritus of any large region of the earth; then, and not till then, we may speculate about their stature, and their manners, and their numbers, as we now speculate among the disinterred ruins of an ancient city.

"We might, I think, rest content with such a general answer as this. But we may advance one step further,—History is a continued record of passions and events unconnected with the enduring laws of mere material agents. The progress of physical induction, on the contrary, leads us on to discoveries, of which the mere light of history would not indicate a single trace. But the facts recorded in history may sometimes, without confounding the nature of moral and physical truth, be brought into a general accordance with the known phenomena of nature; and such general accordance I affirm there is, between our historical traditions and the phenomena of geology. Both tell us, in a language easily understood, though written in far different characters, that man is a recent sojourner on the surface of the earth. Again, though we have not yet found the certain traces of any great diluvial catastrophe, which we can affirm to be within the human period; we have, at least, shown that paroxysms of internal energy, accompanied by the elevation of mountain-chains, and followed by mighty waves desolating whole regions of the earth, were a part of the mechanism of nature. And what has happened again and again, from the most ancient up to the most modern periods in the natural history of the earth, may have happened once during the few thousand years that man has been living on its surface. We have, therefore, taken away all anterior incredibility from the fact of a recent deluge; and we have prepared the mind, doubting about the truth of things of which it knows not either the origin or the end, for the adoption of this fact on the weight of historic testimony."*

Dr. Buckland himself has, at length, abandoned the theory, which, through him, obtained so much celebrity. We will give his recantation, likewise, in his own words, taken from a note on this subject in his *Bridgewater Treatise.*

"The evidence which I collected in my *Reliquiæ Diluvianæ,* 1823, shows that one of the last great physical events which have affected the surface of the earth, was a violent inundation, which overwhelmed great part of the Northern hemisphere; and that this event was followed by the sudden disappearance of the species of terrestrial quadrupeds which had inhabited these regions in the period immediately preceding it. I also ventured to apply the name diluvium to the superficial beds of gravel, clay, and sand, which appear to have been produced by this great irruption of water.

"The description of the facts that form the evidence presented in this volume, is kept distinct from the question of the identity of the event attested by them with any deluge recorded in history. Discoveries which have been made since the publication of this work, show that many of the animals therein described, existed during more than one geological period, preceding the catastrophe by which they were extirpated. Hence, it seems probable, that the event in question was the last of the many geological revolutions that have been produced by violent irruptions of water, rather than by the comparatively tranquil inundation described in the Inspired narrative.

"It has been justly argued against the attempt to identify these two great historical and natural phenomena, that, as the rise of the waters of the Mosaic deluge is represented to have been gradual, and of short duration, they would have produced comparatively little change on the surface of the country overflowed. The large preponderance of extinct species among the animals we find in caves, and in superficial deposits of diluvium, and the non-discovery of human bones along with them, afford other strong reasons for referring these species to a period anterior to the creation of man. This important point, however, cannot be considered as completely settled, till more detailed investigations of the newest members of the Pliocene, and of the diluvial and alluvial formations shall have taken place."

If, then, we be asked, are there no traces upon the earth of the deluge of the Inspired writings? we can only reply, in the words above quoted from Professor Sedgwick, that none have yet been found, and that perhaps it is not intended that they ever should be found; or we may adopt the argument respecting the Mosaic deluge contained in the following extract from Mr. Lyell, who denies that there are sufficient geological data for inferring that instantaneous upheavement of mountain-chains, and of great waves arising therefrom, which are considered by Professor Sedgwick to have removed the anterior incredibility of an historic deluge."

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* Sedgwick's Anniversary Address, 1831;—Proceedings of the Geological Society, vol. i., p. 313.

"I may observe," says Mr. Lyell, "that the reasoning above alluded to seems to proceed entirely on the assumption that the flood of Noah was brought about by *natural* causes; just as some writers have contended that a volcanic eruption was the instrument employed to destroy Sodom and Gomorrah. If we believe the flood to have been a temporary suspension of the ordinary laws of the natural world, requiring a miraculous intervention of Divine power, then, it is evident that the credibility of such an event cannot be enhanced by any series of inundations, however analogous, of which the geologist may imagine that he has discovered the proofs. For my own part, I have always considered the flood, when its universality, in the strictest sense of the term, is insisted upon, as a preternatural event, far beyond the reach of philosophical inquiry, whether as to the causes employed to produce it, or the effects likely to result from it. At the same time, it is clear, that they who are desirous of pointing out the coincidence of geological phenomena with the occurrence of such a general catastrophe, must neglect no one of the circumstances enumerated in the Mosaic history, least of all, so remarkable a fact, as that the olive remained standing while the waters were abating."*

We trust enough has now been advanced to convince the most timid that there is nothing to be feared for the cause of revealed religion from the investigations of geologists, though they ascribe to the earth a higher antiquity than has been supposed to belong to it, in consequence, as we conceive, of an erroneous interpretation of the first two verses of the Bible; or, though they declare that they have not seen on the earth's surface, any traces of a general deluge. No uneasiness is now felt, because the language of Scripture, with respect to astronomical phenomena, is not in accordance with the present state of our knowledge respecting the universe. The explanation offered, in that case, by commentators on the Bible, is that "the Sacred writers were not inspired to speak of natural things with philosophical exactness, but were left to use popular language, and to discourse of them according to their appearances,"† and the only reason that any alarm is felt at the wonders brought to light by geology, is their novelty. When they shall have had the sanction of another century, or even less, they will not be deemed more dangerous to religion than the discoveries of Newton.

It is by no means unusual to commence an elementary treatise with an historical account of the science which forms the subject of it. Following this course, we should now enter into the history of the rise and progress of geology, commencing *ab ovo* with the cosmological opinions of the priests of Egypt and Brahmins of India, and the speculations of the philosophers of Greece and Rome, founded on the obvious fact of the occurrence of marine shells in situations remote from the sea. We should then proceed to show how, when the Roman empire was overthrown by barbarians, geology—such as it was—took refuge in Arabia; and how, on the revival of learning in Europe, it first reappeared in Italy, whence we should trace its progress into Britain, France, and Germany. We should expose the folly, though it passed for wisdom in its day, of the cosmological dreams of Burnet, Whiston, and Buffon. We should show how Werner advanced, and how he retarded, the progress of geological knowledge, and should enter into a history of the controversies which agitated the rival schools of Freyberg and Edinburgh; in which the names of Neptune and Vulcan, of Werner and Hutton, were the watchwords and the rallying cries,—controversies which, to the scandal of science, were conducted, not in the calm spirit of philosophical inquiry, but with all the warmth and intemperance, and bitterness, of a borough election, or a vestry squabble. We should then detail the labours and noble generalizations of Smith and Cuvier, and advert to that grand epoch in the science, the formation of the Geological Society of London; when wearied with the Neptunian controversy, geologists became convinced that the time was not yet arrived, when they could form a true theory of the earth; but that they must be contented, for a long time, to devote themselves to the observation of facts and the accumulation of data for future generalizations; and we should then point out the mighty results which have followed from a steady perseverance in this system, during thirty years, so that the progress of geology has, by these means, been greater during that period, than during the three centuries which preceded it. But to commence a work professing to teach the elements of geology, or of any science, with a history of its rise and progress, appears inconvenient, to say the least of it, because it supposes, in those who are addressed, a certain previous acquaintance with the very subject they require to learn. Our object is to guide our readers into the plain and straightforward road to geological truth, by setting before them the real discoveries of the science; and, surely, that object is not likely to be advanced by first leading them aside into every by-path of error in which they can possibly lose their way, recounting all the absurdities into which men fell, when, giving rein to the imagination, they constructed systems of cosmogony, upon the foundation of a few ill-observed facts, and often without the observation of any facts at all. Our object is to exhibit the amount of light at present possessed by geologists, and it would be but a waste of time to show how, and how long, they groped about in darkness before they found that light.

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* Principles of Geology. 4th edition, vol. iv., p. 219.

† Scott's Bible. Note on Genesis, i. 16.

We agree with Professor Phillips, that " the history of the progress of opinions in geology may be useful as a warning to men advanced in geological inquiries not to reason upon assumptions while facts remain to be explored, and to repress that impatience of spirit, which ever seeks to anticipate observation by the efforts of invention: but that the student ought, if possible, to be kept in impartial ignorance of these conflicting hypotheses, which are apt to fascinate the young and imaginative mind."* We shall, therefore, defer for the present, or wholly omit, a history of the rise and progress of geology; and shall proceed to the consideration of the materials of which the earth's crust is composed, and of the order in which they are arranged.

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* Phillips's Guide to Geology, p. 5.

CHAPTER IV.

Materials composing the crust of the earth.—Simple bodies—their mode of combination—definite proportions—chemical nomenclature.—Simple minerals as distinguished from simple bodies.—The gases—oxygen—hydrogen—nitrogen—chlorine—fluorine.

Although it is not necessary for a geologist to be profoundly versed in chemistry and mineralogy, yet a certain general acquaintance with those sciences is indispensable to the successful prosecution of his own. It will therefore be our endeavour, in the present chapter, to communicate to the geological student something of this necessary chemical and mineralogical knowledge.

The chemist divides all material substances into two classes,—simple and compound. Simple, or elementary substances, are those out of which nothing different from themselves can be obtained; they contain but one kind of ponderable matter. Compound bodies are those which contain two or more elements. We are at present acquainted with but fifty-four bodies to which the title of elementary can be accorded, and out of their combinations arises all that variety of known substances existing in the earth. The list of simple bodies is liable to continual fluctuations, occasioned by the advance of chemical science. Many simple bodies have been discovered within the last thirty years, and more may be expected to be discovered. On the other hand, many supposed elementary substances have, during the same period, been proved to be compounds; and, even now, the chemist entertains suspicions of the compound nature of some bodies, which have hitherto resisted all the resources of chemical analysis to decompose them. These fifty-four bodies are called the simple ponderables;—simple, because we are at present unable to reduce them to more simple forms; ponderable, because, even in their most attenuated state, they possess sensible weight. Hydrogen, which is perfectly invisible, and the lightest substance known, may be confined in proper vessels, and the weight of even a cubic inch of it may be detected by delicate balances. If light, heat, and electricity, be really material substances, and not rather the effects of certain motions, or affections of matter, they are wholly destitute of weight, or, at least, if they possess any, we are unable to discover it, by the most nicely-constructed balances. And yet they appear to be acted on by some of the same powers, under some of the same laws, to which matter is subject, and the phenomena to which they give rise may be explained on the supposition of their being extremely subtle forms of matter. On this supposition, they have received the name of the *imponderables.*

Matter presents itself to our observation under these forms.—the *solid*, the *fluid*, and the *gaseous*, or aeriform. Solids, are bodies whose particles are prevented, by what is called the *attraction of cohesion*, from moving freely among themselves. Fluids, are bodies whose component particles are free to move upon one another, with very slight friction. Aeriform bodies, are lighter than solids and fluids, and their particles appear to be wholly destitute of cohesion. Such bodies are called elastic fluids, because they yield readily to pressure, and expand when the pressure is removed. Non-elastic fluids do not yield perceptibly to ordinary pressure, nor do they dilate perceptibly on its removal.

Solids may be converted into fluids, and fluids into gaseous bodies, by the agency of heat,—as when ice or lead is melted, or mercury converted into vapour, or water into steam; and different substances require different temperatures for the production of these changes. Aeriform bodies which can be condensed by cold and pressure into fluids, are called *vapours;* others are permanently elastic, and by no degree of cold or pressure can they be converted into a less attenuated form. To these only, is the term *gases* properly applied. Oxygen, and hydrogen, of which we shall speak presently, are gases. Chlorine, at ordinary temperatures, is a vapour, which may be compressed into a fluid; and water, which at ordinary temperatures is a fluid, is converted, by the addition of heat, into a vapour.

SIMPLE BODIES.

The fifty-four, or fifty-five* elementary bodies, at present known, may be conveniently classed under the following heads:

Five gases or vapours:—Oxygen, hydrogen, nitrogen, chlorine, and fluorine.

Seven non-metallic solids and fluids:—Sulphur, phosphorus, selenium, iodine, bromine, boron, and carbon.

Three metallic bases of the alkalis:—Potassium, sodium, and lithium.

Four metallic bases of the alkaline earths:—Barium, strontium calcium, and magnesium.

Six metallic bases of the earths:—Aluminum, silicum, yttrium, glucinum, zirconium, and thorium.

Twenty-nine, or thirty, metals, whose combinations with oxygen produce neither alkalis nor earths:—

1 Manganese,
2 Iron,
3 Zinc,
4 Tin,
5 Cadmium,
6 Arsenic,
7 Molybdenum,
8 Chromium,
9 Tungstenum,
10 Antimony,
11 Uranium,
12 Columbium,
13 Nickel,
14 Cobalt,
15 Cerium,
16 Titanium,
17 Bismuth,
18 Copper,
19 Tellurium,
20 Lead,
21 Mercury,
22 Silver
23 Gold,
24 Platinum,
25 Palladium,
26 Rhodium,
27 Osmium,
28 Iridium,
29 Vanadium.

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* A metal, called *Lantanium*, was discovered by Mosander, in 1838.

Of these metals, the first five decompose water at a red heat. The next fifteen do not decompose water at any temperature, and their oxides are not reduced to the metallic state by the sole action of heat. The oxides of the rest are decomposed by a red heat.

A glance at the above list of elementary bodies is sufficient to satisfy us that the larger proportion of them are of a metallic nature. Metals are distinguished by the following characters:—they are conductors of electricity, and of caloric, or heat. When their combinations with oxygen, chlorine, sulphur, or other similar substances, are decomposed by the action of the galvanic battery, the metals always appear at the *negative* pole, and hence are said to be *positive* electrics. They are opaque, not permitting the passage of light, even when reduced to thin leaves. They are, for the most part, good reflectors of light, and have the well-known peculiar lustre, called the metallic.

All the elementary bodies enter into the composition of that great variety of minerals and rocks of which the crust of the earth is composed; some of them occurring in the greatest abundance, others being exceedingly rare. Those which are most abundant, are usually found in combination, seldom in an elementary form. Oxygen, the most abundant of all, does not occur in nature except in combination; and palladium, one of the most rare, is only met with in the metallic state. Few of the elementary bodies are ever found uncombined. The following are all that are ever so found, and then only in small quantities:—Carbon occurs pure, only in the diamond. Native, or pure sulphur, is exhaled from volcanos. Gold, silver, palladium, platinum, mercury, copper, iron, antimony, bismuth and arsenic, are the only metals that have been found in the metallic state.

Chemical Combinations. Notwithstanding the tendency to combination which subsists among the elementary bodies, the substances produced by their combinations are neither so complex, nor so numerous, as might be supposed. Few minerals contain more than five or six elementary constituents, and many contain only two or three. If, indeed, the affinity, or disposition to combine, were equally great between every two of the simple bodies, there might, of course, be as many minerals as there are possible combinations between fifty-four different numbers; and if they combined in all proportions, the number of minerals would be endless; but the affinities vary in degree, so that those substances between which the strongest affinities subsist combine, and thus prevent combinations between those possessing more feeble affinities; and some of the elementary bodies have no affinity for each other, and cannot, by any means, be made to combine. Thus, the affinity of the metallic bases of the alkalis for oxygen is so great, that it is with the utmost difficulty they can be separated from it; or, when separated, preserved long in that state. Gold and platinum, on the other hand, have so weak an affinity for oxygen, that the ores of those metals never occur as oxides.

There is, moreover, another important law of chemical combination, which exercises a powerful influence in limiting the number of compound bodies,—namely, that in all bodies which are not mere mechanical mixtures, but chemical combinations, the ingredients of which they are composed always unite in definite and invariable proportions.

Thus, hydrogen, which is the lightest of all bodies, combines with eight times its weight of oxygen to form water; and this is the lowest proportion in which oxygen enters into combination. Taking, then, hydrogen as unity, the combining proportion of oxygen will be 8, and the combining proportion of water will be 8+1, or 9. The combining proportion of bodies is sometimes called their *atomic weight*, or their *representative number*, or *equivalent.* Again, oxygen and calcium combine in no other proportion than, oxygen 8 parts* + calcium 20 parts = 28 oxide of calcium, or lime. When a body combines with another in more than one proportion, the proportion in each successive compound is an even multiple of the lowest combining proportion. Thus sulphur combines with oxygen in two proportions:—

1 Sulphur 16 parts + oxygen 8 parts = 24 sulphurous acid.
2 Sulphur 16 parts + oxygen 16 parts = 32 sulphurous acid.

Nitrogen and hydrogen afford another exemplification of this law of chemical combination. They form five different compounds:—

1 Nitrogen 14 parts + oxygen 8 parts = 22 nitrous oxide.
2 —— 14 —— 16 = 30 nitric oxide.
3 —— 14 —— 24 = 38 hyponitrous acid.
4 —— 14 —— 32 = 46 nitrous acid.
5 —— 14 —— 40 = 54 nitric acid.

Binary compounds are substances composed of two elementary bodies united in definite proportions, which are well known and invariable. The binary compounds of most frequent occurrence in the mineral kingdom are, alkalis, earths, metallic oxides, alloys or combinations of metals in their metallic state, acids, sulphurets or combinations of bodies with sulphur, and carburets or compounds of bodies with carbon; and when these binary compounds unite, they unite like the simple bodies, in definite proportions. Lime is a binary compound, consisting of calcium 20 parts + oxygen 8 parts = 28 lime, or oxide of calcium. Carbonic acid is likewise a binary compound, consisting of carbon 6 + oxygen 16 (two proportions)=22 carbonic acid, and these numbers 28 and 22 are the proportions in which these two binary compounds, lime and carbonic acid, unite to form carbonate of lime; in every 50 grains of which there are 28 of lime and 22 of carbonic acid. Now, though carbonate of lime is a compound of two binary compounds, it contains but three elementary substances, calcium, oxygen, and carbon. It is, therefore, called a ternary compound. This is a very extensive and important class of bodies, comprehending most of those substances termed salts.

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* Parts always mean parts by weight.

Chemical Nomenclature. It is necessary in this place to say something respecting the modern system of chemical nomenclature; and Dr. Turner's explanation of it is so clear and elegant, and at the same time so concise, that it would be unpardonable either to attempt an abridgment of it, or to offer any sketch of our own. "Chemistry," he says, "is indebted for its nomenclature to the labours of four celebrated chemists, Lavoisier, Berthollet, Guyton-Morveau, and Fourcroy. The principles which guided them in its construction are exceedingly simple and ingenious. The known elementary substances, and the more familiar compound ones, were allowed to retain the appellations which general custom had assigned them. The newly-discovered elements were named after some striking property. Thus, as it was supposed that acidity was always owing to the presence of the 'vital air' discovered by Priestley and Scheele, they gave it the name of *oxygen,* derived from the Greek words signifying generator of acid; and they called 'inflammable air' *hydrogen,* from the circumstance of its entering into the composition of water.

"Compounds of which oxygen forms a part, were called *acids,* or *oxides,* accordingly as they do or do not possess acidity. An oxide of iron, or copper, signifies a combination of those metals with oxygen which has no acid properties. The name of an acid was derived from the substance acidified by the oxygen, to which was added to the termination *ic.* Thus, sulphur*ic* and carbon*ic* acids, signify acid compounds of sulphur and carbon with oxygen gas. If sulphur, or any other body, should form two acids, that which contains the least quantity of oxygen is made to terminate in *ous,* as sulphur*ous* acid. The termination in *uret* was intended to denote combinations of the simple non-metallic substances, either with one another, with a metal, or with a metallic oxide. Sulph*uret* and carb*uret* of iron, for example, signify compounds of sulphur and carbon with iron. The different oxides or sulphurets of the same substance, were distinguished from one another by some epithet which was commonly derived from the colour of the compound, such as the black and red oxides of iron, the black and red sulphurets of mercury. Though this practice is still continued occasionally, it is now more customary to distinguish degrees of oxidation by derivatives from the Greek. *Prot*oxide signifies the first degree of oxidation, *deut*oxide the second, *trit*oxide the third, and *per*oxide the highest. The sulphurets, carburets, &c., of the same substances are designated in a similar way. The combinations of acids with alkalis, earths, or metallic oxides, were termed *salts,* the names of which were so contrived as to indicate the substances contained in them. If the acidified substance contains a maximum of oxygen, the name of the salt terminates in *ate;* if a minimum, the termination *ite* is employed. Thus sulph*ate,* phosph*ate,* and arseni*ate,* of potash, are salts of sulphur*ic,* phosphor*ic,* and arsen*ic* acids; while the terms sulph*ite,* phosph*ite,* and arsen*ite* of potash, denote combinations of that alkali with the sulphur*ous,* phosphor*ous,* and arseni*ous* acids.

"The advantages of a nomenclature which disposes the different parts of a science in so systematic an order, and gives such powerful assistance to the memory, is incalculable. The principle has been acknowledged in all countries where chemical science is cultivated; and its minutest details have been adopted in Britain. It must be admitted, indeed, that in some respects the nomenclature is defective. The erroneous idea of oxygen being the general acidifying principle, has exercised an injurious influence over the whole structure. It would have been convenient also to have had a different name for hydrogen. But it is now too late to attempt a change; for the confusion attending such an innovation would more than counterbalance its advantages. The original nomenclature, therefore, has been preserved, and such additions have been made to it as the progress of the science rendered necessary. The most essential improvement has been suggested by the discovery of the laws of chemical combination. The different salts formed of the same constituents were formerly divided into *neutral, super*, and *sub*-salts. They were called neutral, if the acid and alkali are in proportion for neutralizing one another; super-salts, if the acid prevails; and sub-salts, if the alkali is in excess. The name is now regulated by the atomic constitution of the salt. If it be a compound of one equivalent of the acid to one equivalent of the alkali, the generic name of the salt is employed without any other addition; but if two or more equivalents of the acid be attached to one of the base, or two or more equivalents of the base to one of the acid, a numeral is prefixed so as to indicate its composition. The two salts of sulphuric acid and potash are called sulphate and *bi*-sulphate; the first containing one equivalent of the acid to one equivalent of the alkali, and the second salt two of the former to one of the latter. The three salts of oxalic acid and potash are termed the oxalate, *bin*-oxalate, and *quadro*-oxalate of potash; because one equivalent of the alkali is united with one equivalent of acid in the first, with two in the second, and with four in the third salt. As the numerals which denote the equivalents of the acid in a super-salt are derived from the Latin language, Dr. Thomson proposes to employ the Greek numerals *dis, tris, tetrakis,* to signify the equivalents of alkali in a sub-salt. This method is in the true spirit of the original framers of our nomenclature. Chemists have already begun to apply the same principle to other compounds besides salts; and there can be no doubt that it will be applied universally, whenever our knowledge shall be in a state to admit of its introduction."*

The above account of the present system of chemical nomenclature explains the nature of the substances enumerated in our list of binary compounds, under the names of acids, oxides, sulphurets, and carburets. It will, however, be as well to describe the characteristic properties which distinguish acids and alkalis.

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* Turner's Elements of Chemistry, p. 125.

Alkalis have a peculiar pungent taste; they neutralize acids; they change some vegetable blues to green; they change to a reddish brown the yellow colour of paper stained with turmeric; and they restore the blue colour of litmus paper reddened by the action of acids.

Acids are compounds capable of uniting in definite proportions with alkaline and earthy bases, and, when in a state of solution, they either have a sour taste, or redden litmus paper. Most acids contain oxygen as one of their elements, which was therefore supposed, at one time, to be the acidifying principle; but acids exist which have no trace of oxygen, and there are bodies (water, for instance,) which contain a large proportion of oxygen without possessing acid properties. Those acids in which hydrogen is one of the elements, are called hydracids.

In analyzing a mineral, it is sufficient if we ascertain the nature and proportions of the binary compounds of which it consists; and the results of an ultimate analysis may then be deduced from calculation. Thus having ascertained that 50 parts of carbonate of lime contain 28 parts of lime and 22 of carbonic acid, and knowing that carbonic acid consists of carbon 6 + oxygen 16 parts, we find that in 50 parts of carbonate of lime, reduced to its simplest constituents, there are 20 parts of calcium, 6 of carbon, and 24 of oxygen.

SIMPLE MINERALS DISTINGUISHED FROM SIMPLE BODIES OF THE CHEMIST.

When we speak of simple minerals, we use the term simple in a different sense from that in which it is used by the chemist. He applies it only to those bodies which resist all the powers of chemical analysis to decompose them. The mineralogist, on the other hand, sees, aggregated in rocks, certain minerals distinguished from each other by peculiar characters. He can separate them from one another by mechanical means, and in this separate state he makes them his study, and calls them simple, because he cannot reduce them to a more simple state, except by means of chemical analysis.

Marble, or carbonate of lime, is, in this view, a simple mineral, because, although we reduce it to the finest possible powder, we have still nothing but fine particles of carbonate of lime, each consisting of lime and carbonic acid, and it is only by subjecting it to the action of heat or acids that we can obtain these elements in a separate form. If we expose carbonate of lime for a considerable time to a red heat, we drive off the carbonic acid, and oxide of calcium remains; the loss of weight indicating the quantity of carbonic acid expelled. Or, if, into a small flask containing diluted muriatic acid, the weight of the flask and acid being ascertained, a known quantity of carbonate of lime, reduced to small fragments, be gradually introduced (care being taken to prevent any of the liquid from being thrown out by effervescence), the diminution of weight experienced by the flask and its contents will indicate the quantity of carbonic acid which the carbonate of lime contained; the lime now remaining in solution as muriate of lime, from which it may be separated by the proper re-agents.

Granite is a compound rock, consisting of three minerals. By slightly pounding a piece of this rock in an iron mortar we may separate these, and may proceed to examine those characters which distinguish them from each other, and from other minerals. We may determine their specific gravity, or the weight of each compared with an equal bulk of water. We may ascertain the shape of their crystals, if they occur regularly crystallized; or if only confusedly crystallized, the shape of the primitive form of their crystals,—that is, the shape into which they may be reduced by dividing them in directions parallel to the planes of natural cleavage. We may examine their hardness indicated by their yielding, or not yielding, to the nail, the knife, or the file; by their scratching glass, or giving sparks with steel. We may try whether they are brittle, tough, flexible, or elastic. We may examine their colours, and other relations to light, as opacity, transparency, translucency, and refraction. We may ascertain their lustre, and the aspect of a fresh fracture; also, whether they feel unctuous to the touch; whether they have any taste or smell, or adhere to the tongue; whether they are affected by the magnet, or, when excited by heat or friction, whether they exhibit electric properties, or appearances of phosphorescence. We are thus furnished with a list of external characters by which we may discriminate minerals. We may thus distinguish the constituents of granite from one another, and from other minerals; we may distinguish mica from talc, and from a plate of selenite, to which it has some general resemblance; and we may distinguish quartz from felspar, from calcareous spar, from carbonate of manganese, from fluor spar, and from sulphate of barytes, with all of which it is liable to be confounded by persons not conversant with mineralogy.

Having ascertained that granite is a compound of three minerals, quartz, felspar, and mica, we have recourse to chemical analysis, as in the case of carbonate of lime, in order to determine the elementary substances of which each of those minerals is composed. Our mode of proceeding, however, must be somewhat different, since each of these minerals contains several elementary substances, and since they are not soluble in acids. In order, therefore, to bring them into a state of solution, we take a given quantity, 50 or 100 grains for instance, of one of them, previously reduced to very fine powder, and fuse it in a platinum crucible, with three or four times its weight of alkali, which, uniting with one or more of the constituents of the mineral, effects its decomposition. The fused mass is now soluble in water, or diluted muriatic acid, and, by the application of different re-agents, its constituents are successively precipitated, separated from the solution by filtration, carefully dried and weighed, and their separate quantities being added together, ought to be equal to the weight submitted to analysis, a trifling allowance being made for unavoidable waste; and thus the composition of quartz, felspar, and mica, is found to be:—

Quartz.—Almost wholly silica, combined with 2 or 3 per cent. of water.

Felspar:—	Silica	63·74
	Alumina	17·14
	Lime	3·00
	Potash	13·06
	Loss and water	3·06
		100·00

Mica:—	Silica	53·75
	Alumina	24·62
	Potash	21·35
		99·72
	Loss	·28
		100·00

Thus, the province of the chemist with respect to minerals is to resolve them into their elements, and to investigate the properties of these, and the laws of their combination. The mineralogist makes the minerals themselves the objects of his study, investigating their characters, and the properties by which they are distinguished, and he thus learns to discriminate them when aggregated in rocks. It is in this, their aggregated state, as masses, and in their relations to other similar masses, that they become subjects of investigation to the geologist, who observes whether they occur stratified, unstratified, or in veins: and he endeavours to discover the agencies employed in their formation, and the epochs at which they were formed; only studying the minerals of which they are composed, and the elements of those minerals, so far as they may tend to throw light on those inquiries. In granite, for instance, he sees a crystalline, unstratified rock, composed of quartz, felspar, and mica, forming the foundation on which the stratified rocks rest, and also rising through them, and forming the summits of lofty mountains. He observes that it has frequently sent off veins into the superincumbent rocks, and seeing the nature of the changes produced in these at the point of contact with the granite, and their disturbed and inclined position in the neighbourhood of it, he is led, in speculating on the mode in which that rock was formed, to infer that it was once in a state of fusion, and that it was the agent employed in the upheavement of chains of mountains, and in placing in their inclined and elevated position beds of rock containing marine remains, which must have been formed at the bottom of the ocean, and in a horizontal position. Having observed, moreover, that rocks which, in different localities, have suffered disturbance in the vicinity of granite, belong to different geological epochs, evinced by their different groups or organic remains, he concludes that all the granite in the world was not formed at one and the same time, but that there have been ejections of it at various periods.

Such, then, are the different trains of investigation to which the same substances give rise in the hands of the chemist, the mineralogist, and the geologist. Let is now enter into the consideration of some of the elementary substances, which are of the most importance as ingredients of the crust of the earth.

THE GASES.

OXYGEN. At the head of this list stands oxygen, which combines with so many substances, and enters so largely into the composition of many minerals, and those the most common ingredients of rocks, that it may be said to form half of the ponderable matter of which the exterior parts of the globe consist. It constitutes 8 parts out of 16 of silica, 8 parts out of 18 of alumina, 8 parts out of 28 of lime, 8 parts out of 20 of magnesia, 8 parts out of 48 of potash, and 8 parts out of 32 of soda. It is an essential element of many acids. United with carbon, in the proportion of 16 to 6, it forms carbonic acid, which constitutes nearly half of carbonate of lime, which has been estimated as one-eighth of the crust of the globe. Oxygen forms 8 parts out of 9 of water, and enters extensively into the composition of many of the ores of manganese, tin, lead, iron, and copper; but it is never met with except in combination with some other substance.

A large portion of the atmosphere consists of oxygen, deprived of which, it loses its power of supporting animal life. Oxygen is not inflammable, but a supporter of combustion. Every substance that will burn in atmospheric air, burns with far greater brilliancy in oxygen gas. Even iron and steel undergo rapid combustion in it. Combustion is a combination of oxygen with the burning body, and the products of combustion in oxygen gas, or atmospheric air, are oxides.

Oxygen, in its elementary state, is an invisible, permanently-elastic gas, without taste or smell, a feeble refractor of light, and a non-conductor of electricity. When the compounds of oxygen are submitted to the action of a galvanic battery, the oxygen is always determined to the positive pole, and is therefore said to be negatively electric. Its combining proportion has already been stated to be 8.

HYDROGEN. Hydrogen is the lightest of all known material substances, and is taken as the standard of comparison for the specific gravity of the gases, as water is for that of solids and liquids. It is by no means an important element in the composition of rocks. It is, like oxygen, an invisible and permanently-elastic gas. It is highly inflammable; combined with sulphur it forms sulphuretted hydrogen, which, as well as hydrogen itself, is emitted from the earth in volcanic regions. Sulphuretted hydrogen, when absorbed by water, communicates to it the peculiar properties of the Harrowgate and other sulphureous springs. That species of limestone called swinestone, is supposed to derive its fetid odour when rubbed, from the presence of sulphuretted hydrogen. Combined with carbon, hydrogen forms carburetted hydrogen, which issues in large quantities from between beds of coal, and produces those fatal explosions known to miners by the name of fire-damp. Hydrogen constitutes 1 part in 9 of water. Water is contained in most minerals as an accidental ingredient, either enclosed in cavities, as in rock crystal, calcedony, and flint, or absorbed by most earthy and porous minerals; but it is also chemically combined with many minerals, both crystalline and massive, as an essential ingredient. These combinations with water are called hydrates; and when water forms an essential ingredient of a crystallized mineral, it is called its water of crystallization. Hydrogen is a positive electric with respect to oxygen, chlorine, and that class of bodies, but negative with respect to the metals. It is a powerful refractor of light. It soon causes death to an animal that breathes it. Its combining proportion is 1.

Nitrogen. Nitrogen is likewise a permanently-elastic, invisible gas, without taste or smell. It is not combustible, but extinguishes burning bodies that are plunged in it. It is incapable when respired, of supporting animal life; and yet, diluted with oxygen, in the proportion of 8 parts of oxygen to 28 of nitrogen, it forms atmospheric air, so essential to life. Air is not a chemical combination of these gases, but a mechanical mixture of them. A chemical combination of oxygen and nitrogen, in proportions which we have before stated, constitutes nitric acid, one of the most violent and poisonous of that class of bodies. Nitrogen combined with hydrogen forms ammonia, a volatile substance, which possesses all the properties of an alkali. The sulphate and muriate of ammonia are exhaled from volcanos. Nitrogen, in the state of nitric acid, enters into the composition of nitrate of potash, which is an abundant production of the earth in various parts of France, Germany, Italy, Spain, Hungary, Persia, India, and America. Its combining proportion is 14.

Chlorine. Chlorine is a yellowish-green vapour, of an astringent taste, and disagreeable odour. It is perfectly irrespirable, exciting spasms and irritation of the throat, even when much diluted with atmospheric air. It may be condensed by cold and pressure into a yellow liquid. It has a violent action on some of the metals, which, when introduced, in the state of powder, or in fine leaves, into chlorine, are inflamed and enter into combination with it. It is known in the mineral kingdom as one of the constituents of chloride of sodium, or rock-salt. We have likewise ores of lead, mercury, and silver, which are chlorides of those metals; but it never occurs uncombined. With hydrogen it forms muriatic acid, which is one of the components of the salts called muriates. Muriate of soda, which by evaporation is converted into chloride of sodium, is the principal ingredient in sea-water, which likewise contains muriate of magnesia. These two salts are also found in many saline springs. Muriate of ammonia has already been spoken of as a volcanic product. Chlorine is a negative electric. Its name is derived from its greenish colour (χλωρος). Its combining proportion is 36.

Fluorine. The substance to which this name has been given has never been obtained in an insulated form, and there is a difference of opinion among chemists, whether Derbyshire spar should be considered as a compound of calcium and fluorine, or of oxide of calcium and an acid of which fluorine is one of the elements. To this acid the name of fluoric was given, and it was supposed to consist of fluorine and oxygen, but the experiment of Sir Humphrey Davy, since repeated by other chemists, affords strong presumption that fluor spar is a direct combination of fluorine and calcium, and that the acid produced when these two elements are separated by means of aqueous sulphuric acid, consists of fluorine united to hydrogen, derived from the water of the sulphuric acid. It has therefore received the name of hydrofluoric acid. It possesses the property of dissolving silica, and consequently of corroding glass. Fluor spar is an abundant mineral production. The hydrofluoric acid is also found in the cryolite, and a few other rare minerals. Fluorine is a negative electric. Its combining proportion is 18.

CHAPTER V.

SIMPLE BODIES.—CONTINUED.

Non-metallic solids and fluids—sulphur—phosphorus—iodine—bromine—selenium—boron—carbon.—The alkaline metals—potassium—sodium—lithium. —Metallic bases of the alkaline earths—barium—strontium—calcium—magnesium.—Bases of the non-alkaline earths—aluminum—silicum—yttrium—glucinum—zirconinm—and thorinum.

Sulphur. Sulphur is a brittle solid, of the specific gravity 1·99, or about twice the weight of water. It is of a yellow colour, emitting, when rubbed, a peculiar and well-known odour, but has little taste. It is highly combustible, burning with a blue flame, and suffocating vapour. It is found in many parts of the earth, both massive and crystallized, particularly in the neighbourhood of volcanos. The largest supplies of it are obtained from the Solfaterra, near Naples, which is the crater of an extinct volcano. It is found, however, much more abundantly in combination with the metals iron, copper, lead, silver, and antimony.

The sulphurets are the commonest ores of most of the metals. Sulphur is procured artificially in large quantities by exposing sulphuret of iron to a red-heat, and collecting the sulphur which sublimes. Combined with oxygen it forms sulphuric acid, which, united with alkalis, earths, and metallic oxides, gives rise to a class of salts called sulphates, which are abundant mineral products. Sulphate of barytes, or heavy spar, and sulphate of lime, or gypsum, are common. Sulphate of strontian is less so. The sulphates of magnesia and soda are frequently contained in mineral springs. Sulphate of iron, or green vitriol, sulphate of copper, or blue vitriol, and sulphate of zinc, or white vitriol of commerce, are occasionally found crystallized accompanying the sulphurets of those metals, but are much more common in the water issuing from mines where the sulphurets are raised in large quantites. A decomposition of the sulphurets is caused by atmospheric agency. Oxygen combines with the metal to form an oxide, and with the sulphur to form sulphuric acid; and the acid and the oxides unite, and produce sulphates.

If a bar of iron be immersed in a solution of sulphate of copper, it will soon be coated with a film of metallic copper. The acid, having a greater affinity for the iron than for the copper, unites with the former, and the latter is precipitated. Much copper is by this process obtained at the Parys mine in Anglesey, and some other mines, where the decomposition of large quantities of ore too poor for smelting, causes the water issuing from the mines to be charged with sulphate of copper, the metal of which is precipitated by the water being made to pass through large tanks filled with old iron. Sulphur is a non-conductor of electricity, and a negative electric. Its combining proportion is 16.

Phosphorus. Phosphorus is a soft tenacious solid, nearly colourless when pure. It is highly inflammable, burning with a pale yellow flame, and undergoing slow combustion at the ordinary temperature of the atmosphere. The product of its combustion is phosphoric acid. Phosphoric acid enters into the composition of several minerals, namely, the phosphates of lime, lead, copper, manganese, and iron. Phosphorus is a negative electric. Some uncertainty prevails respecting its combining proportion. It is considered to be 18.

Iodine, bromine, and selenium, are of little importance in the mineral kingdom, however interesting on account of their chemical properties. Iodine, which is derived from the ashes of seaweeds, is found in the waters of some mineral springs combined with soda and magnesia, and iodides of zinc, mercury, and silver, are said to have been discovered in some of the Mexican mines.[*] At ordinary temperatures, it is a soft friable substance, opaque, of a bluish colour, and a metallic lustre. It is a negative electric, and a non-conducter of electricity. It sublimes rapidly at a low heat, with a vapour of a very rich violet-colour, whence its name.[†] Its combining proportion is 124.

Bromine. This substance was discovered by M. Balard of Montpellier, in 1826. In its chemical relations, it bears a close analogy to chlorine and iodine, being always associated with the former, and sometimes with the latter.

It exists in sea-water, and in some mineral springs in Germany, and has been found in the ashes of sea-weeds, and of several plants that grow on the shores of the Mediterranean.

Bromine, at ordinary temperatures, is a liquid of a blackish-red colour when viewed in mass, but of a hyacinth-red by transmitted light. Its action on some of the metals is similar to that of chlorine. It is a non-conductor of electricity, and a negative electric. Its combining proportion has not been ascertained.

Selenium. Selenium, at common temperatures, is a brittle solid, opaque body, without taste or odour, of a metallic lustre, having the aspect of lead in mass, of a deep-red colour when reduced to powder. Its specific gravity is between 4·3 and 4·32. The Swedish chemist Berzelius, by whom it was discovered, supposed it to have been a metal; but being a non-conductor of electricity, it is more properly classed with the non-metallic bodies. It may be detected by the peculiar powerful odour, like that of decayed horseradish, which it emits when heated. It was found mixed with the sulphur sublimed from the iron pyrites of Fahlun, in Sweden. It is a negative electric, and a non-conductor of electricity. Its combining proportion is 40.

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[*] Beudant, Traité de Mineralogie, tom. ii., p. 515.

[†] Ἰώδης—violet-coloured.

Boron. Boron is a dark olive-coloured substance, without either taste or smell, about twice the weight of water, infusible and not volatile, and insoluble in water. On being heated, it suddenly takes fire, oxygen disappears, and boracic acid is formed. It was first obtained by Sir Humphry Davy, by exposing boracic acid to the action of a galvanic battery. Boracic acid, which is therefore a compound of boron and oxygen, occurs as a natural product in the hot springs of Lipari, and of Sasso, near Florence. It is also a constituent of two very rare minerals, boracite, or borate of magnesia, and datholite, or borate of lime. Boracic acid combined with soda, is collected in considerable quantities on the shores of some lakes in Thibet and Persia, whence it is imported into Europe, through India, under the name of tincal, which, after being refined, is the borax of commerce. Its chief use is as a flux for some of the metals, for which purpose it is of great importance in the analysis of minerals by the blowpipe. Boron is a non-conductor of electricity, and a negative electric. Its combining proportion is 8.

Carbon. Carbon is the peculiar inflammable principle of charcoal, which is the product of wood heated to redness in close vessels, or under such circumstances as to exclude the air: and the diamond is carbon in absolute purity.

Newton was led to suspect the diamond to be combustible, from its great powers of refraction, and modern chemists have confirmed the conjecture by effecting its combustion. Its product, when burned in oxygen gas, is carbonic acid; and when burned in contact with iron, it converts it into steel, producing the same effects as are produced by charcoal under similar circumstances.

Carbon enters into the composition of coal, bitumen, and amber, and of the inflammable liquids, naphtha and petroleum. Black lead, or plumbago, is a native carburet of iron. But the most important office performed by carbon in the mineral kingdom is as the base of carbonic acid, which is generated when carbon is burned in oxygen gas, and constitutes, as we have before observed, 22 parts out of 50 of that abundant rock, carbonate of lime.

Carbonic acid is absorbed by water, of which it is deprived by being boiled. Hence the agreeable and refreshing flavour of spring-water, and the insipidity of water that has undergone the process of boiling. Water saturated with carbonic acid sparkles when poured from one vessel into another, such are the waters of the mineral springs of Tunbridge, Pyrmont, Carlsbad, and many others.

Carbonate of lime is very sparingly soluble in water, but dissolves in an excess of carbonic acid; hence water, charged with that acid, percolating through limestone, dissolves a portion of the rock, which it again deposits by the dissipation of the acid.

This is the origin of those pendent masses, like large icicles, called stalactites, which are so abundant in caverns in limestone, and also of calcareous tufa, deposited by springs. Among the most remarkable calcareous springs, are those of San Filippo, in Tuscany, at which a curious manufactory of medallions in basso-relievo is established. The water of these springs is hot, and holds in solution a large quantity of carbonate of lime. After being made to pass through a series of pits, in which its coarser matter is deposited, it is conducted to the summit of a chamber in which numerous cross sticks are placed, to break the fall of the water, and disperse the spray as much as possible. This falls on moulds placed to receive it, and a deposit of solid carbonate of lime is formed upon them, and thus most beautiful casts are obtained. Some idea may be formed of the immense quantity of calcareous matter which these springs contain, from two circumstances mentioned by Mr. Lyell respecting them; namely, that they deposit a stratum of hard stone a foot thick in four months, and that on the side of the hill is a mass of travertin, as this stone is called, a mile and a quarter long, a third of a mile broad, and at least 250 feet thick. The petrifying properties of many springs in England are similar to those of the waters of the baths of San Filippo, though exhibited on a much smaller scale,—the substances said to be petrified by immersion being covered by an incrustation of carbonate of lime. A similar deposit takes place in boilers and tea-kettles, from the dissipation of the carbonic acid by the boiling of the water causing a precipitate of calcareous matter. The springs of limestone countries are frequently rendered unwholesome by the quantity of carbonate of lime which their waters hold in solution. But it is not of limestone only, that carbonic acid is a solvent. It has a decomposing effect upon many other rocks, particularly those which contain felspar, and it renders oxide of iron soluble in water. It exudes from the earth, and collects in pits, caverns, and old wells. It is, when respired, destructive to animal life; and, as it is incapable of supporting combustion, its presence, in too great quantities to be breathed without fatal effects, may be detected by the introduction of a lighted candle into the suspected place, which ought not to be entered if that is extinguished. Exhalations of carbonic acid gas are most abundant in volcanic countries. The Grotto del Cane, near Naples, celebrated for the cruel exhibition of its effects on dogs, for the gratification of the curiosity of idle tourists, owes its destructive qualities to the evolution of carbonic acid gas.

Carbon is a negative electric, and a conductor of electricity. Its combining proportion is 6.

THE ALKALINE METALS.

We come now to the alkaline metals, potassium, sodium, and lithium. Until the year 1807, the two fixed alkalis, potash and soda, (for lithia had not then been discovered,) had baffled all attempts of chemists to decompose them. The discovery of their elements was a triumph reserved for Davy, who, wielding the potent energies of the voltaic pile, evoked, as with the wand of an enchanter, a new class of metals out of substances the metallic nature of which had not till then been suspected. But if we liken the galvanic battery to the wand of a magician, the metals evoked by it may be compared to spirits obeying with reluctance the summons that called them to the light of day, and vanishing almost as soon as they appear; or, to drop the language of metaphor, their affinity for oxygen is so great, that they return to the state of an oxide in a few minutes, and they are with difficulty preserved in the metallic state long enough for the investigation of their characteristic properties.

Potassium. When hydrate of potassa, slightly moistened, is connected with the opposite poles of a galvanic battery, the oxygen, both of the water and the potassa, passes over to the positive pole, while hydrogen and potassium appear at the negative. Potassium is solid at the ordinary temperature of the atmosphere, becomes partially fluid at 50°, and completely so at 150°. In colour and lustre it resembles mercury, but differs from other metals in being lighter than water. Its powerful affinity for oxygen has already been spoken of. It oxidizes rapidly in the air, or in fluids containing oxygen. It decomposes water the instant it touches it, the potassium being inflamed, and burning with a vivid light while swimming on the surface. It can only be preserved from oxidation by being kept in glass tubes hermetically sealed, or by being immersed in liquids which do not contain oxygen as one of their elements. Its combining proportion is 40. Potash, or potassa, the oxide of potassium, is found combined, in small quantities, with nearly twenty earthy minerals, among others, with mica and felspar. It also combines with some acids. Nitrate of potash, or saltpetre, has already been spoken of as a mineral product, under the head of Nitrogen.

Sodium. Sodium was discovered by Sir Humphry Davy shortly after the discovery of potassium. It has a strong metallic lustre, like that of silver, and is so soft at the common temperature, that it may be pressed into leaves with the fingers. It soon oxidizes when exposed to the air, though less rapidly than potassium. When thrown into water it swims on the surface with a violent hissing noise, and is rapidly oxidized, hydrogen being evolved, but no light is visible. It possesses the characteristic properties of other metals, in being a positive electric. Its combining proportion is 24. Soda, the oxide of sodium, is found in variable proportions in about twelve earthy minerals, but in none that are metallic. It combines abundantly with several acids. The borates, carbonates, sulphates, and muriates of soda, have been already noticed, under the heads of boron, carbon, sulphur, and chlorine.

Lithium. A new alkali, to which the name of lithia was given, was discovered in the year 1818, by a Swedish chemist, in analyzing a mineral called petalite; it has also been found in spodumene, and in several varieties of mica. Lithia was decomposed by Sir H. Davy, by the same means which had effected the decomposition of potash and soda, and a white metal resembling sodium was obtained, which was reoxidized, and thus converted into lithia, so rapidly that it could not be collected. Its combining proportion is 10.

METALLIC BASES OF THE ALKALINE EARTHS.

The four earths, baryta, strontia, lime, and magnesia, possess alkaline properties, but they are less caustic than the alkalis, are not fusible, except by voltaic electricity, or the hydro-oxygen blowpipe, are less soluble in water than the alkalis, and form, with carbonic acid, insoluble compounds. These earths are reduced to the metallic state with much greater difficulty than the alkalis, and the properties of their bases have not been so well ascertained.

Barium. Sir H. Davy obtained this metal by mixing carbonate of baryta in a paste with water, and placing a globule of mercury in a hollow on its surface, and then bringing it in contact with the opposite poles of a galvanic battery. The barium of the baryta formed an amalgam with the mercury, and on submitting it to heat in close vessels, from which the air was excluded, the mercury sublimed. Barium has only been obtained in small quantities, and its properties have therefore scarcely been determined with precision. It is of a dark-gray colour, with less lustre than cast-iron, and its specific gravity is greater than that of water. It attracts oxygen rapidly from the atmosphere, and yields a white powder, which is baryta. Barium effervesces strongly in water, with disengagement of hydrogen. Its combining proportion is 70.

Baryta, or barytes,* so called from the weight of its compounds, is a gray powder, about four times heavier than water. It has a sharp alkaline taste, converts vegetable blues to green, and neutralizes acids. All the soluble salts of baryta are poisonous. Sulphate of baryta is one of the most insoluble substances with which the chemist is acquainted. Baryta is by no means a very abundant earth. Its salts communicate a yellow colour to flame.

Strontium. This metal was discovered by Sir H. Davy, by a process similar to that employed to obtain barium. Little more is known respecting it than that it is a heavy metal resembling barium, and that it is converted into strontia by contact with water or air. Its combining proportion is 44. Strontia, like the other earths, is white when dry and pure, and resembles baryta in its infusibility and alkaline properties. The salts of strontia, when dissolved in alcohol, and inflamed, tinge the flame of a blood-red. Strontia occurs combined with carbonic and sulphuric acids. Its name is derived from Strontian, in Scotland, where the carbonate was first discovered.

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* Βαρυς—heavy.

Calcium. The existence of the metallic base of lime was proved by Sir H. Davy, by the means before described as employed for the decomposition of baryta and strontia. It is whiter than barium, and is converted into lime by oxidation. Its other properties are unknown. Its combining proportion is estimated at 20.

Lime, or oxide of calcium, has never been found pure: when prepared by the chemist it is white and caustic, and changes vegetable blues to green. It is infusible, except by the hydro-oxygen blowpipe or by voltaic electricity. When a stream of oxygen gas is directed upon red-hot lime, it produces a light too intense to look upon.

Lime is a most important and abundant earth. It is prepared in large quantities by exposing the carbonates of lime, such as limestone, marble, chalk, calcareous spar, or sea-shells, to a red heat, when the carbonic acid is driven off, and lime remains. In this state it is caustic, and is called quick-lime. When moistened with water, it falls to powder and combines with the water. It then becomes a hydrate of lime, commonly called slaked lime, in which state it is used for mortar.

The importance and utility of lime and its compounds is as great as its distribution is extensive. Its use as a manure, a cement, and for many other purposes in the arts, is too well known to require enumeration. Besides the carbonate, lime occurs as a fluate, borate, and arseniate.

Magnesium. The existence of this metal was likewise proved by Sir H. Davy, though he obtained it in quantities too minute for ascertaining its properties, any further than that it decomposes water, and that its oxide is magnesia. Its combining proportion is 12.

Magnesia is a white powder, and, when pure, has neither taste nor odour. It is of the specific gravity of 2·3, and very infusible. It forms a hydrate with water, for which, however, it has a less affinity than lime. It is sparingly soluble in water. The solution of magnesia is inert with respect to vegetable blues, but when pure magnesia is laid on turmeric-paper, it causes a brown stain. This is a decided proof of its alkalinity, and it possesses another essential alkaline property, that of forming neutral salts with acids.

Magnesia is found in about thirty minerals, but they are not so abundant as in the compound of lime or silica, nor does it form the prevailing ingredient in any of them. Minerals containing magnesia have frequently a soapy feel. It is found in combination with the carbonic, sulphuric, and boracic acids. The mineral in which it exists in the greatest purity is the hydrate, called also native magnesia.

THE NON-ALKALINE EARTHS.

Aluminum. From some experiments of Sir H. Davy, it was inferred that the earth alumina is a metallic oxide; and aluminum, the metal, has lately been procured in a pure state by Dr. Wöhler. It is a gray powder, very similar to that of platinum, occurring generally in small scales of metallic lustre. It requires for its fusion a higher temperature than that at which cast-iron melts. When heated to redness in the open air, it takes fire, and burns with a vivid light; aluminous earth, of a white colour and considerable hardness, being the result. When heated to redness in a vessel of pure oxygen, it burns with intense light and heat, the resulting alumina is partially vitrified, and equal in hardness to corundum, an aluminous crystallized mineral.

Water, at common temperatures, does not oxidize aluminum, but oxidation commences when the water is heated to near the boiling-point; and a feeble disengagement of hydrogen takes place. Aluminum is not a conductor of electricity in the state of powder, but becomes so when fused. The earth alumina, in its pure state, has neither taste nor smell, is quite infusible, and insoluble in water, for which, however, it has a powerful affinity, forming with it a hydrate. It attracts moisture from the atmosphere, and adheres strongly to the tongue. When once combined with water, it cannot be rendered anhydrous, except by a white heat.

Alumina is a very common earth: it occurs in every country, and in rocks of all ages, and the aluminous rocks are among the most abundant in every formation. It is an important ingredient in soils, imparting to them tenacity and the power of retaining moisture. Those soils in which it forms the chief ingredient are termed stiff, or clayey, and are best adapted to the growth of wheat.

When mixed with water, hydrate of alumina forms a soft plastic mass, easily moulded into various forms, and capable of being hardened in the fire, and hence its utility in the manufacture of pottery. Although hydrate of alumina, or clay, is a very abundant mineral product, yet in a state of purity it is extremely rare, being generally contaminated with silica, lime, or oxide of iron, the presence of which latter ingredient causes the red colour of most kinds of clay when burned. Marl is a mixture of clay with calcareous matter. Rocks in which alumina prevails may be recognised by the earthy smell which they give out when breathed upon. This is called the argillaceous odour, though it does not belong to alumina in a state of purity. Alumina occurs combined with the hydro-fluoric and sulphuric acids, and with potash and soda. Though the most common form of alumina is a rude, amorphous, soft clay, it likewise occurs crystallized. Those beautiful gems, the ruby and the sapphire, consist almost wholly of alumina, and rival the diamond in hardness and in value. This earth likewise amounts to 86 per cent. in corundum or emery, which is so hard as to be employed in polishing steel, and in cutting and polishing gems. The name of alumina is derived from alum, of which it is the base. In these minerals alumina appears like silica in the silicates to act the part of an acid, and they have therefore by some chemists been named aluminates.

Silicum. The metallic base of the earth silica was obtained by Sir H. Davy, by bringing the vapour of potassium in contact with pure silica, heated to whiteness, when a compound of silica and potassa was formed, through which the base, silicum, was diffused in black particles like plumbago. Nevertheless, much doubt existed whether it was a metal, and some chemists classed it among the non-metallic bodies, under the name of sili*con*. The recent researches of Berzelius appear nearly decisive of this point. He first obtained the base of silica in a state of purity, and found it a solid, of a dark nut-brown colour, without the least metallic lustre; and it wanted another characteristic of a metal, that of being a conductor of electricity. Its combining proportion is 8.

Silica is the most abundant of the earths. In its pure state silica is a light white powder, without taste or odour, and feels rough and dry when rubbed between the fingers. It is infusible, except by the oxy-hydrogen blowpipe, to which it yields more readily than either lime or magnesia. Silica is quite insoluble in water, which, however, dissolves it in large quantities in its nascent state. In order that silica should be held in solution in springs, it appears necessary that the water should be at a high temperature. The most celebrated hot siliceous springs are those of St. Michael, one of the Azores, and of the Geysers in Iceland, from each of which is deposited a siliceous incrustation called sinter, analogous to the calcareous tufa which we have before described as resulting from waters containing carbonate of lime.

Silica appears to possess the properties of an acid rather than an alkali. No acid acts upon it except the hydrofluoric, but it is dissolved by solutions of the fixed alkalis, and combines with many of the metallic oxides. Some chemists, therefore, among whom is Berzelius, denominate silica *silicic acid*, and its compounds with alkaline and earthy bases and oxides, *silicates*. The compound earthy minerals containing silica, are in this view native silicates.

When silex, or pure sand, is fused with carbonate of soda or potassa, carbonic acid is expelled, and a silicate of the alkali produced; the nature of which varies according to the proportions of alkali employed. If the compound consist of one part of silica and three parts of alkali, a vitreous mass will be formed, soluble in water; but on reversing the proportions, a brittle transparent compound is formed, not soluble in water, nor in any acid except the hydrofluoric. This is glass. Every kind of glass is composed of silica and an alkali, and the quality of it depends on the purity or impurity of the materials used. Silica forms a component of two-thirds of the earthy minerals, whose composition is known. As quartz-rock, it constitutes whole mountain-masses. It is the princidal ingredient of sandstones. Rock-crystal, calcedony, flint, and jasper, consist almost wholly of it, and silica of sufficient purity for most purposes may be procured by heating rock-crystal, throwing it when red-hot into water, and then reducing it to powder. The name of silica is derived from *silex*, the Latin for flint.

The remaining earths, yttria, glucina, and zirconia, ocur too rarely, and are consequently too little known, to require or admit of much description. They are supposed from analogy to have metallic bases like the other earths, but they have never been decomposed.

Yttrium is the supposed base of the earth *yttria*, which was discovered as a component of a mineral called gadinolite, found near Ytterby, in Sweden, whence the name of yttria. Sir H. Davy demonstrated that oxygen entered into the composition of yttria, by bringing it, when ignited, into contact with potassium, when the oxygen of the yttrium united with the potassium and formed potassa, and dark metallic particles were diffused through the alkali. It is found only in one or two rare minerals besides the gadinolite. Its combining proportion is estimated at 36.

Glucina derives its name from the Greek word γλυκυς, *sweet*, from the sweet taste of its salts. When pure, it is a white powder without taste or odour, soft, and quite insoluble in water. The metallic nature of its base has been inferred on the same grounds as that of yttria, and its combining proportion has been estimated at 36. Glucina occurs only in small quantities, combined with other elements in the minerals euclase, beryl, emerald, gadinolite, and topaz.

Zirconia is an earth discoverd in the zircon of Ceylon, and the hyacinth of Expailly, in France, as a white powder (when pure) resembling alumina in its appearance, and without either taste or odour. Its specific gravity is 4.3. Like the other earths, it is infusible by ordinary means. The experiments of Sir H. Davy led to a presumption that its base was of a metallic nature, and Berzelius has since procured it in an insulated state, in the form of black powder. Its metallic nature is very doubtful; it may be pressed out into shining scales, but has not been procured in a state capable of conducting electricity. Its combining proportion appears to be 40.

The substance called *thorina*, which Berzelius supposed to be a distinct earth, he afterwards found to be a phosphate of yttria; but a black heavy mineral has lately been discovered near Brevig in Norway, which proved, on analysis, to be a silicate of a new earth, allied in its properties to yttria, glucina, and zirconia, and to the base of this earth Berzelius has given the name of thorium.

The twenty-nine metals which close the list of simple bodies, are to be considered rather as accidents of rocks than as their essential ingredients. For this reason, although they are a most useful, important, and interesting class of substances, we shall not enter into a description of them. When it is said that they are not essential ingredients of rocks, an exception must be made with respect to iron, the oxide of which is of almost universal distribution, there being scarcely a mineral in which it is not found in small quantities. With respect to the relative abundance of the earths, silica is the most common, alumina the next so. Lime occurs among the earlier rocks, but is most abundant in the stratified secondary series, and with the increase of lime a corresponding increase appears to have taken place in the number of testaceous molluscs.

CHAPTER VI.

EXTERNAL CHARACTERS OF MINERALS.

Minerals discriminated by their external and chemical characters.—External characters—irregular forms—regular forms or crystals—primary and derived forms—fracture — hardness—frangibility—transparency—lustre — colour—flexibility—elasticity—double refraction—touch—taste—odour—powder—stain—adhesion to the tongue—magnetism—electricity—phosphorescence—specific gravity.

Having described the most remarkable properties of the elementary bodies in their relation to the crust of the earth,—having pointed out the distinction between the simple bodies of chemistry and simple minerals,—and having taken a cursory glance at some of the characters by which minerals are discriminated, we will now resume this latter part of the subject more in detail, and will describe those minerals which enter most extensively into the composition of rocks. It must be premised, however, that the student desirous of obtaining a knowledge of mineralogy will learn more in a few weeks from oral instruction, and from the careful observation of well-arranged collections, than he can in months, or even years, from the most elaborate descriptions, unaccompanied by examination of the substances described.

Facilities for the study of mineralogy have of late greatly increased. Public collections of minerals were, a few years ago, confined to the metropolis, the capitals of Scotland and Ireland, the universities, and one or two of the chief principal towns. To those, therefore, who resided at a distance from such public collections, or from teachers of mineralogy, that science was, in a great measure, a sealed book. Their only resource was to purchase from dealers named collections of minerals, the expense of which amounted to a prohibition with the majority of students, or to pick up information, slowly and laboriously, by examining such specimens as chance might throw in their way, and by comparing them with the descriptions in works on mineralogy. But now the case is greatly altered. There are now few counties in Great Britain in which Natural History Societies have not been established, and some of the larger and more opulent counties support two or three. Minerals must ever form a prominent object in Museums of Natural History; and a useful and instructive collection of these, although too costly for most individual students, may be purchased for a sum which becomes trifling when divided among a number of contributors.

Minerals may be discriminated by their *External* and by their *Chemical* characters; and chemical analysis is of two kinds,—*Qualitative* and *Quantitative.* By means of the former, we merely seek to ascertain what ingredients are to be found in any substance; by means of the latter, we determine the quantities in which these different ingredients are combined. As the chemical characters depend on the composition of minerals, these can only be thoroughly known by means of a complete quantitative analysis; but a rough qualitative analysis will frequently afford considerable insight into their composition, and furnish a series of characters, many of which are peculiar to certain minerals, or groups of minerals, and are thus of great assistance for the discovery of their nature when any ambiguity arises in the external characters. This qualitative analysis may be performed upon a small scale, both cheaply and expeditiously, either in the dry or the humid way. In the first process, small fragments of the mineral to be examined are submitted to the action of heat. The heat employed is that of a lamp or candle, urged by a blast through a blowpipe, this blast being sustained, most commonly, by the lungs of the operator, but sometimes by bellows or other apparatus. The blowpipe is a small tube seven or eight inches long, a quarter of an inch in diameter at its widest end, and gradually contracting till it terminates at the other in an orifice of the size of a small wire. By means of this instrument, an intense heat, equal in degree to that of the most powerful wind-furnace, may be produced. Many earthy minerals may be fused by it; and the ores of many metals may be reduced to the metallic state; and blowpipe operations have this advantage over those conducted in a furnace,—that the whole process takes place immediately under the eye of the operator, who can thus observe all the changes produced by the action of heat upon the mineral under examination, when treated either alone or with the addition of borax, carbonate of soda, or other fluxes. These changes are termed the habitudes of a mineral before the blowpipe, and are of great value as distinctive characters. We can, by these means, distinguish felspar from quartz,—the former being fusible, the latter infusible, unless mixed with an alkali. A sulphuret may be known from an arseniuret by the different odours which they exhale when heated, and the different metals communicate peculiar colours to the glass formed by their fusion with borax.

In conducting a qualitative analysis in the humid way, a small portion of the mineral reduced to powder is submitted to the action of a few drops of acid in a watch-glass, heat being applied from the flame of a lamp or candle, if necessary; and if the mineral can thus be brought into a state of solution, the solution is diluted with water, and poured into several small glass tubes, to each of which a different test or reagent is added, and by each of these, peculiar changes are produced in the solution, according to the nature of the substances contained in it.

We shall first describe the external characters of minerals;

then the mode of ascertaining their chemical characters by the blowpipe and with acids; and lastly, enumerate the most common of the earthy minerals, giving both their external and chemical characters.

THE EXTERNAL CHARACTERS.

These are Form, Structure, Fracture, Frangibility, Hardness, Transparency, Translucency, Lustre, Colours, Flexibility, Elasticity, Double Refraction, Touch. Taste, Odour, Streak or Powder, Stain, Adhesion to the tongue, Magnetism, Electricity, and Specific Gravity or Weight.

With respect to *Form*, a mineral is either without any particular form, when it is said to be *Amorphous;* or it bears some general resemblance to common substances, natural or artificial, in which case it is said to have a *Particular Form;* or its natural surfaces consist of a certain number of planes of a determinate shape, arranged in a determinate manner, in which case it is said to be *Crystallized*, or of a *Regular Form.*

A mineral which occurs in pieces not exceeding the size of a hazel-nut imbedded or incorporated in another mineral, is said to be *Disseminated*, whether it be amorphous or crystallized. If amorphous, and in pieces larger than a hazel-nut, it is said to be *Massive.* When the size of the pieces is from that of a hazel-nut to that of a pea, it is said to be *Coarsely* disseminated; from the size of a pea to that of a grain of mustard-seed, it is *Finely* disseminated; and when the pieces are below that size, and still perceptible by the eye, it is *Minutely* disseminated. An amorphous mineral that occurs loose or detached is said to be *in Grains*, which are distinguished according to their size, as *Gross*, *Large*, *Small*, and *Minute.* Gross grains are from the size of a hazel-nut to that of a pea: large, from the size of a pea to that of hemp-seed; small, from the size of hemp-seed to that of mustard-seed; below which size they are called minute. An amorphous mineral that occurs adhering to another mineral in flattened pieces which do not exceed an inch in thickness, is said to be *in Plates.*

Particular external forms are those which bear a resemblance to common well-known bodies, both natural and artificial. The following are the names given to different particular forms.

Dentiform. When a mineral adheres by the thicker end, is elongated towards the other end with a curve, and terminates in a point, it is said to be dentiform, or tooth-shaped. From the Latin *dens*, a tooth.

Filiform. A mineral is said to be filiform that occurs in long slender columns, like wires or threads. From the Latin *filum*, a thread.

Capilliform. When the threads are more slender, like hairs, the mineral is called *capilliform.* From the Latin *capillus*, hair. These columns or threads are, in fact, imperfect crystals. When a mineral occurs in long, slender, well-defined crystals, it is said to be *acicular,* or needle-shaped.

Retiform. This term is applied to parallel threads or fibres intersecting other parallel threads or fibres at right angles, and producing the appearance of network. From the Latin *rete,* a net.

Dendritic. This is synonymous with arborescent, and is applied to a mineral which from a thicker main stem separates into several which are more slender, and are often furnished with smaller shoots, presenting, on the whole, the appearance of a tree, whence the name, from the Greek δενδρον, *a tree.* We have dendritic native silver and copper, and dendritic manganese, which is of very common occurrence on the surface of natural joints in rocks.

Ramose. This is that particular form which consists of crooked branches, not rising from a common stem, nor possessing a proportionate thickness. From the Latin *ramus, a branch.*

Coralliform. A mineral occuring in elongated curved shoots, rounded at the extremities, is said to be coralliform, from its resemblance to coral.

Stalactitiform. A mineral resembling an icicle in shape is said to be stalactitiform, from the Greek σταλαγμα, *a drop, an icicle.*

Tubuliform, or *fistuliform,* are terms applied to minerals occurring in round and hollow columns, single or in groups. From the Latin *tubulus* and *fistula,* a pipe.

Botryoidal, resembling a cluster of grapes. From the Greek βοτρυς, a grape. Minerals presenting an aggregation of large sections of small globes are called botryoidal. This particular form occurs in calcedony, manganese, and malachite, or green carbonate of copper. When the globes are larger, and the sections or portions smaller, the term *Mammillated* is used. From the Latin *mamma,* a breast.

Reniform. A mineral is said to be reniform when it consists of several globular elevations, each of which is sometimes composed of several that are smaller. The name is derived from the Latin *ren,* a kidney, from the resemblance to kidneys, particularly those of calves. Red and black hæmatite are good examples of this form.

Specular. A mineral not crystallized, and having one smooth and brilliant surface, is called specular. Specular galena, or slickensides, affords an example. Some crystallized minerals are also said to be specular, from the brilliancy of their planes, as specular iron ore. From the Latin *speculum,* a looking-glass.

Laminated. A mineral is said to be laminated, when it occurs in thin plates or leaves adhering to another mineral. From the Latin *lamina,* a thin plate.

Pectinated. This form is produced by tables disposed upon and beside each other, so that they present the appearance of hair parted by the comb. From the Latin *pecten,* a comb. It is of very rare occurrence.

Cellular. This term is properly applied to minerals which exhibit the appearance of cells formed by the crossing and intersecting of the laminæ of which they are composed. It is, however, frequently used instead of *Vesicular*.

Vesicular. This term belongs to a mineral having small and somewhat round cavities, both externally and internally, as in lava, pumice, and basalt. It is derived from the Latin *vesicula*, a little bladder.

REGULAR FORMS OR CRYSTALS.

When a body passes from the gaseous, or fluid, to the solid state, the particles of which it is composed sometimes arrange themselves together so as to form a shapeless mass; but they more commonly dispose themselves in a certain order, so as to give rise to solids whose surfaces consist of a determinate number of sides, associated in a determinate manner. Such bodies are called crystals, and the process by which they are formed is termed crystallization. This process takes place when a solid has been fused, and is allowed to return slowly to the solid form, or when it has been dissolved in a fluid from which it is slowly deposited by evaporation; and the more slowly this cooling or evaporation takes place, the more regular are the forms of the crystals. As an instance of crystallization from solution, add alum to eight or ten ounces of boiling water as long as any is dissolved, and on allowing the liquid to cool, crystals will be deposited; or, dissolve oxalic acid in water, and on exposing it to the air for some days in a shallow vessel, part of the water will be evaporated, and crystallization will take place. As an instance of crystallization from a state of fusion, melt a quantity of sulphur in a large crucible, and when it is partially cooled, pierce the solid crust, and, inverting the crucible, let the fluid parts run out. When it is quite cold, regular crystals of sulphur will be found in the interior. The regularity of the crystals in this case arises partly from their having had free space to form in, as well as from the slowness of cooling, for confused crystallization may frequently be seen in the centre of a roll of sulphur. The crystallization occurs in that part because it was the longest in cooling, and it is imperfect, first, because the cooling even of the interior of so small a mass takes place too rapidly for the formation of any but irregular crystals, and secondly, because they have no vacant space in which to arrange themselves without interfering with one another. Something analogous is met with occasionally in granite. That rock is an irregularly crystallized mass of quartz, felspar, and mica, like the imperfect crystallization in the stick of sulphur, but some kinds of granite, as that of the Mourne Mountains in Ireland, abound in cavities in which those minerals are found in regular crystals. The most perfect crystals of mineral veins are always found lining similar cavities.

Crystallography, or the study of the forms and structure of crystals, is an extremely interesting and important department of science, by which mineralogy is connected with mathematical investigations and the most refined optical researches.

It has been found that certain forms are so far peculiar to certain minerals and salts as to constitute grounds of distinction between them.

Calcareous spar crystallizes in rhomboedrons, fluor spar in cubes, and quartz in six-sided pyramids; but fluor spar is never found in rhomboedrons, nor calcareous spar and quartz in cubes.

The surfaces which bound the figure of a crystal are called planes or faces. They are most commonly flat. The lines formed by the junction of two faces are called edges. The angle formed by the junction of two edges is called a *plane angle.* The point formed by the meeting of at least three planes is termed a *solid angle.* Thus in the cube (fig. 4), *a a a* are planes, *b b b* are edges, and *c c* are solid angles. *Lateral planes* are those of the greatest extent, considered as parts of the surface, and they bound it towards its smallest extent. *Extreme* or *terminal* planes are those of the smallest extent as parts of the surface, and form its confines towards its largest extent. Lateral edges are formed by the junction of lateral planes with lateral planes. Terminal or extreme edges are formed by the junction of lateral planes with terminal edges. Thus, in the right square prism (fig. 5), *a a* are lateral planes, *b b* terminal planes, *c c* lateral edges, *d d* terminal edges. Crystals sometimes present the appearance of having lost their edges and solid angles, which are then said to be *replaced* by tangent planes. A *tangent plane* with reference to an edge means a plane inclined equally to the two adjacent primary planes, and parallel to the edge which it replaces. With reference to a solid angle a tangent plane is inclined equally to all the planes constituting the solid angle. When an edge is replaced by two small converging planes, terminating in an edge, it is said to be *bevelled.* When a solid edge is replaced by three or more converging planes, it is said to be *acuminated.*

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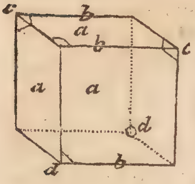

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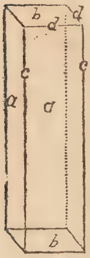

The forms of crystals are divided by crystallographers into *primary,* (called also *primitive, fundamental,* or *derivative,*) and *secondary* (or *derived*) forms. This distinction is founded on the relation of certain geometrical solids to each other,—on the transitions from one form to another exhibited by many minerals—from the replacement or truncation of their edges and solid angles,—and on the facility with which most crystallized minerals split in certain directions, so that, however various the forms of their crystals, they may be all reduced by cleavage into some simpler form, having smooth shining planes like the natural faces of a crystal. If the solid angles of a regular octoedron (fig. 6) be cut off, truncated or replaced, as in fig. 7, and if these planes be equally enlarged till the faces of the octoedron disappear, a cube will be formed; or if the twelve edges of the octoedron be replaced by tangent-planes, as in fig. 8, and if these be extended till they mutually intersect, the rhombic dodecaedron, fig. 9, will be produced. In the same manner, if the eight solid angles of the cube be replaced, as in fig. 10, by equilateral triangles, and if these be extended till the planes of the cube disappear, the octoedron, fig. 6, will be the result. The tetraedron, fig. 11, may be formed by the replacement of the four solid angles, *cc*, *dd*, of the cube, fig. 4, till the cubic faces are destroyed, and the rhombic dodecaedron, fig. 9, may be formed by replacing all the edges of the cube, as in fig. 12, with tangent-planes, till they intersect.

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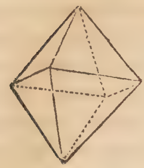

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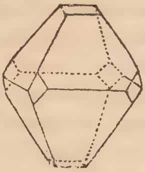

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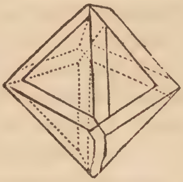

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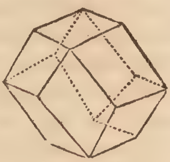

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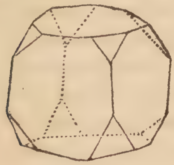

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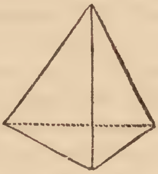

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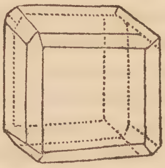

In order to render these relations more familiar, and to show the variety of secondary forms which may be produced by combinations of the planes of different primary forms, let the student cut cubes and octoedrons out of an apple or a turnip, and practise the replacement of their solid angles and edges described above, till the cube results out of the octoedron, and the octoedron out of the cube.

For an enumeration of the other primary forms, which are differently stated by different authors, and for an account of all the secondary forms derived from them, we must refer to works on crystallography. Not only is there this relation between certain geometrical solids, so that by the truncation of their edges and solid angles one may be derived from the other, but the intermediate forms occur in nature. Cubic and octoedral crystals, for instance, are met with, in which the replacement is so slight that the general form of the octoedron or cube remains, (see figs. 7 and 10) while in others the replacement is so deep that the primary planes are hardly distinguishable.

In speaking thus, it is not meant, that the edges and solid angles have actually been removed, but only that the same appearances have been produced as if these truncations had taken place. The probable way in which the modification of the primary form has resulted from the addition to the primary planes of the crystal of laminæ gradually diminishing in breadth, will be adverted to presently.

But further, however various may be the crystalline forms under which the same mineral occurs, and however distant may be the localities from which different specimens of it may have been brought, if they yield to cleavage at all, they may all be cleaved so as to afford the same nucleus or primary form. Calcareous spar is found crystallized under three hundred varieties of form at least; but these may all be cleaved in three directions, and in those directions only, so as to give bright surfaces like the faces of a crystal; and those cleavages are so inclined to each other as to produce an obtuse rhomboid, having plane angles of invariable measurements. Into this form, and no other, are all crystals of carbonate of lime cleaveable, and therefore this is justly considered as its primary form. The primary forms of some other minerals have been established on more arbitrary grounds. Fluor-spar, may be cleaved in four directions, so as to produce three different forms, the regular octoedron, the regular tetraedron, and an acute rhomboid; out of these crystallographers have selected the first as the primary, though for what reason is not very apparent. Crystals of blende, or sulphuret of zinc, may be cleaved into five different forms, one of which has been fixed on as the primary. There are other minerals whose crystals admit of cleavage in only one direction; and yet to these and to others which are not susceptible of cleavage in any direction, primary forms have been assigned. In such cases, primary form has been deduced from the direction of natural fissures or joints which become visible when a very thin slice of the mineral is held up between the eye and the light, or it has been inferred from analogy by comparing the crystalline forms of the substance under investigation with others whose primary forms are well ascertained.

We have spoken of the formation of the cube out of the octoedron, and of the octoedron out of the cube, by the replacement of their solid angles; but either of these bodies may be formed upon the other, by the addition of layers parallel to the planes of the original solid, such layers gradually diminishing in breadth. For example, when cutting off the solid angles of a cube, and extending the planes produced thereby, if we preserve the layers successively removed, and fasten them on again, we shall have the cube formed upon the octoedron by addition, as the octoedron was formed out of the cube by diminution; and in the same manner, after reducing the octoedron to the cube, we may form the octoedron on the cube, by restoring the layers which had been cut off.

When, therefore, we speak of the modification of the primary form of a crystal by the replacement, or truncation, of its edges and solid angles, we merely adopt a fiction which affords a convenient mode of describing effects produced by a process of which we are ignorant, such process having, in all probability been the very reverse of that indicated by the terms employed. For there are good grounds for considering the secondary forms of crystals as having arisen from the regular arrangement on the planes of the primary forms, of laminæ of crystalline matter, gradually decreasing in breadth, such laminæ being made up of extremely minute particles, all of the same form, in the same manner that a pyramid may be built of regularly-diminishing horizontal courses of small cubical bricks, each course or layer being a plate of the thickness of a single brick. A pyramid built of such bricks would of course, present the rough channelled outline seen in fig. 13, instead of the smooth polished faces of a crystal; but if each of these bricks were (as we may conceive the integrant molecules of crystals to be) so small that the inequalities produced by them were not discernible, the faces of the pyramid would appear as smooth as those of a crystal.

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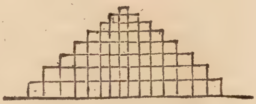

The form of ultimate particles which are so small as to be invisible, opens, of course, a wide field for conjecture. It is, however, certain, that secondary crystals may be cleaved into layers parallel to the planes of a primary nucleus of a different form (in some large and coarse crystals these layers are visible, being marked by striæ on its surface); these layers may be divided by cleavage in other directions, so as to afford small bodies of a determinate shape; these again may be divided and subdivided into small solids, all of the same shape, till they are no longer discernible without the aid of a lens; and they still preserve their peculiar shape as long as they are visible. These forms, then, whether cubes, octoedrons, &c., are considered as the forms of the constituent molecules of which the crystals are built up.

By placing a low three-sided pyramid on each plane of the regular octoedron, a rhombic dodecaedron may be formed, as in fig. 14, in which the strong lines mark the octoedral nucleus, and the fainter lines the planes of the dodecaedron, each of which is a rhomboid composed of two triangular planes, belonging to two different pyramids. On one face of the primitive are also marked the progressively-decreasing layers of which the pyramid is made up.

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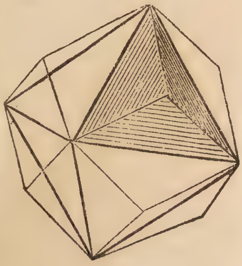

The rhombic dodecaedron may also be formed by placing a low quadrangular pyramid on each face of the cube, as in fig. 15; and the pentagonal dodecaedron, fig. 16, may likewise be formed on the cube, by placing on each of its faces an equal and similar pyramid, having two triangular and two quadrangular planes, as in fig. 17. Now, in the formation of these two different dodecaedrons on the cube, if the integrant molecules (*the bricks*) of which the two kinds of pyramid are composed be all of a cubic form, there must be a very different arrangement of them in the two cases; for in the rhombic dodecaedron, the faces of the pyramid are all equal, and inclined on the faces of the cube at the same angle; but in the pentagonal dodecaedron, the faces of the pyramids are only equal and similar in pairs *a* to *a′* and *b* to *b′*, and they are inclined on the planes of the cube at different angles. These angles have been measured by instruments called goniometers, and calculations have been made for determining the mode of aggregation of particles of the same shape necessary to produce these different forms; and it has been ascertained, by these means, that the pyramids of the rhombic dodecaedron must be composed of layers or molecules placed in regular order, each layer being of the thickness of one molecule, and each successive layer diminishing regularly by the breadth of one molecule on each side; but that in the case of the pentagonal dodecaedron, the layers of its pyramids must be of the thickness of two molecules, and must diminish in breadth unequally on the two sides; that is to say, on the side of the quadrangular plane they must diminish two molecules in breadth for one of height, and of the side of the triangular plane they must diminish one molecule in breadth for two of height, as shown in fig. 18. The Abbé Haüy investigated in like manner the angles under which the secondary planes would meet, arising from gradual decrement in the dimensions of successive layers of crystalline matter deposited on the other geometrical solids as the primary

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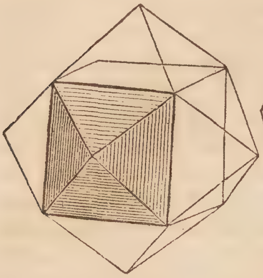

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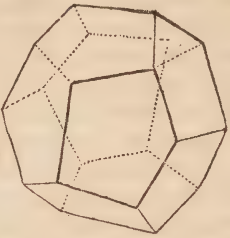

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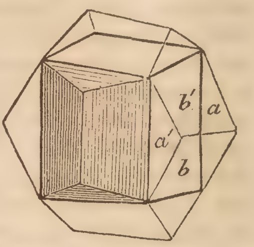

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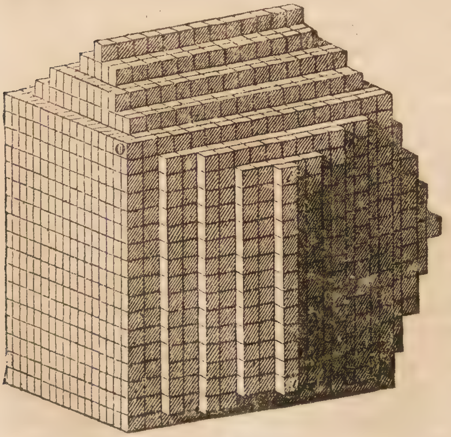

nucleus. He may be considered as the founder of crystallography. Guided by the accidental fracture of a crystal of calcareous spar, he discovered that all crystals have a primary form, which may be extracted from them by mechanical division. He calculated the modifications of which those primary forms are susceptible, and determined the combinations of integrant molecules necessary to produce different forms of crystal with molecules of the same shape, and to produce like forms with molecules of different shapes; and in all cases it has been found, that the results obtained by measurement of the angles, and by calculation, mutually confirm each other.

On these grounds it is inferred, that regularity of external form arises from regularity of internal structure, dependent on the combination, under definite laws, of minute ultimate particles of determinate shapes.

Crystalline form and structure are, therefore, of too much importance to be passed over wholly unnoticed, in an account of the external characters of minerals, and it has been impossible to give even the above imperfect outline, without entering into considerable detail. At the same time it must be acknowledged, that crystallography must be considered as affording a field for refined and curious research, rather than as furnishing, to any but experienced mineralogists, available practical rules for discriminating minerals. In calcareous spar, and some other substances, the ease with which they may be reduced to the primary form renders it a good distinctive character; and a knowledge of the crystalline forms in which certain minerals are most commonly found, will often assist in identifying a mineral with which we are unacquainted, when it is rendered ambiguous by the possession of several external characters in common with other minerals; but, in general, before the student can be able to obtain much information by cleaving crystals into their primary forms, and measuring their angles, he will have learned, by other means, the names and composition of most, if not all, the minerals which are of much importance to the geologist. The beginner, therefore, whose object is to discover the names of minerals of which he is ignorant, and the working geologist, who most commonly meets with them massive, or only irregularly crystallized, must have recourse to a combination of characters more obvious, though individually less definite, than the measurement of the angles of crystals.

The discovery, by Professor Mitscherlich, of what is called the *isomorphism* of crystals, diminishes in some degree the value of crystalline form as a distinctive character, since he has found that certain bodies may be substituted for each other in combination, without affecting the form of the crystals. Phosphate and biphosphate of soda crystallize in the same forms as the arseniate and binarseniate of the same alkali; and each arseniate has a corresponding phosphate, possessed of the same form, and containing the same equivalents of water, acid, and alkali.

Hence, those bodies which crystallize in the same forms have been arranged in groups, called isomorphous groups. The salts of arsenious acid are isomorphous with those of phosphoric acid; oxide of lead, baryta, and strontia, afford, in combination with the same acid, isomorphous salts; and the salts of lime, magnesia, protoxide of manganese, iron, cobalt, oxide of zinc, and oxide of copper, are all isomorphous.

We will now explain the terms applied by mineralogists to crystals when aggregated in groups, and then proceed to consider the remaining external characters.

Crystals are said to be *fasciculated,* when they occur aggregated in small bundles. From *fascis*, Latin, a bundle.

Scopiform, is a term applied to a number of minute crystals or fibres closely aggregated into a bundle, and diverging slightly from a common centre. From the Latin *scopa,* a broom.

Stellated. Minerals are said to be stellated, when their crystals or fibres diverge all round a common centre. From the Latin *stella*, a star.

Drusy. Minerals are said to be drusy, when their surface is composed of very small and prominent crystals, nearly equal to each other in size. The name is derived from the German.

Investing. This term is applied to a mineral which coats or covers another.

FRACTURE. We have shown that most minerals split more easily in certain directions than in others, and that they may thus be reduced in the direction of natural joints into figures, bounded by planes of a smooth shining surface, and a determinate shape. This is their cleavage. The surface produced by breaking them in directions contrary to these natural joints, is called the fracture; and its appearance, which is dependent on the composition of a mineral, forms in most cases a good distinctive character.

The surface of a fracture is said to be *compact*, when no particular or distinct parts are discernible. It is the most common kind of fracture, and is divided into *splintery*, *even*, *conchoidal*, *uneven*, *earthy*, and *hackly*.

The surface is *Splintery*, when destitute of any remarkable elevations, but small splinters, or scales, are discernible, thickest at the end by which they adhere, and terminating at the other in an edge. This kind of fracture occurs in hornstone, many varieties of quartz, and some sorts of limestone.

Even is that kind of fractured surface which is nearly flat, and destitute of elevations, such as occur being indeterminate in shape, and flat. It passes into splintery and conchoidal.

Conchoidal surfaces consist of round elevations and depressions, accompanied sometimes by circular wrinkles, having something of the appearance of a shell. It is divided into the *perfect* and *imperfect*, *flat* and *deep*, *large* and *small*, conchoidal. The best examples of this kind of fracture occur in the most pellucid kinds of quartz, in opal, flint, obsidian, and cannel-coal.

Uneven. The surface of this kind of fracture is completely broken, and interrupted by irregular and rather large angular elevations and depressions. It is met with in the gray and yellow sulphurets of copper, and many other minerals.

Earthy. The surface of the earthy fracture is composed entirely of small rough elevations. It is most common in indurated clay, chalk, and the earthy minerals.

Hackly. In this kind of fracture sharp-pointed parts protrude from the internal surface. It is peculiar to the malleable metals. The fracture of metallic copper is a good example.

Sometimes the fracture presents the appearance of an aggregation of fibres, which are frequently the result of imperfect crystallization, and are either *coarse*, *large*, *small*, *fine*, or *delicate*, *curved*, *straight*, *parallel*, *diverging*, or *promiscuous*.

The diverging fibrous fracture is divided into *Stellated* and *Scopiform*, the meaning of which has been already explained.

The fibres are *Promiscuous*, when they intersect each other in various directions. We have examples of this structure in alabaster and red hæmatite; of the stelliform fibrous, in some kinds of hæmatite and fibrous zeolite; of the scopiform, in fibrous malachite; and of the promiscuous, in gray antimony.

The fracture is said to be *Striated*, when it is marked by narrow grooves or channels. Examples occur in some kinds of sulphuret of iron, in actynolite, and hornblende. The striated, like the fibrous structure, is parallel, stellated, scopiform, and promiscuous.

Foliated, or *Lamellar*, is a term applied to the fracture of those minerals, that are composed of thin leaves or plates laid upon one another. Mica, talc, and micaceous iron, are instances of it.

Slaty. Uncrystallized minerals that split only in one direction, affording fragments that have parallel sides, but are of unequal thickness, not smooth, and destitute of lustre, are said to possess a slaty fracture.

HARDNESS. Minerals are found under every degree of hardness, from that of the diamond, the hardest of known substances, down to the fluid state of mercury and naphtha. The different degrees of hardness in minerals are estimated by their scratching or not scratching one another or glass, and by their yielding or not yielding to the file, the knife, and the nail. Calcareous spar will scratch selenite (or crystallized gypsum); fluor-spar will scratch calcareous spar; felspar will scratch fluor-spar, calcareous spar, and selenite; and fluor-spar will not scratch glass, which receives an impression from quartz and felspar. Several of the gems again scratch quartz, and among them different degrees of hardness exist, determined by their making or not making an impression on one another. The giving of sparks with steel is sometimes considered a test of hardness; but it is by no means a good criterion, for flint gives more numerous and brilliant sparks than many substances which are much harder. Minerals are said to be

Extremely hard, on which the file makes no impression.

Very hard, if they receive a weak impression from the file,—such are quartz, flint, and topaz.

Hard, if they receive a considerable impression from the file, but cannot be scraped by the knife,—such as felspar and schorl.

Half-hard minerals yield to the knife, as calcareous spar, limestone, fluor-spar, and many others. By yielding to the knife is not meant a capability of being divided along natural joints, so as to produce smooth and shining surfaces; but the receiving of an impression when scratched or scraped in directions contrary to those joints.

Soft minerals may be easily scraped with the knife, but receive no impression from the nail. Such are, sulphate of baryta, mica, asbestos, and amber.

Very soft minerals are those which yield to the nail, as gypsum chalk, and chlorite.

Sectile minerals are those which may be cut into slices with a knife, the new surface thus produced being smooth and shining. Examples occur in plumbago and soapstone.

FRANGIBILITY. This is a property distinct from hardness, for flint, which is much harder than hornblende, is much more brittle. Different degrees of frangibility may be observed, from hard to tough and malleable. The integrant particles of brittle minerals are, in the highest degree coherent or immovable among themselves; they are distinguished by the ease with which they are converted into fragments by a blow, and by the fine dust which arises from them on the powerful application of a knife. All hard, many half-hard, and some soft, minerals are brittle. Tough materials are bruised and suffer depression from a blow, and are with difficulty reduced to fragments. Hornblende, basalt, and, in general, all minerals containing hornblende or augite, are remarkable for their toughness. Malleability is the property of suffering extension when beaten with a hammer, and is confined to those minerals possessing a metallic lustre.

TRANSPARENCY. This character varies considerably in the same substance, and even in different parts of the same specimen. A mineral is said to be *transparent*, when objects may be distinctly seen through it; *semi-transparent*, when they cannot be seen through large, but only through small pieces, and then but indistinctly. The difference between transparent and translucent minerals is best seen by laying them on printed paper, and observing the distinctness of the letters seen through them. When an object is not visible through a mineral, and in the mass it is quite impervious to light, we shall yet sometimes find, on holding it between the light and the eye, that it is *translucent at the edges*. When this is not the case, it is described as *opaque*.

LUSTRE. Lustre is the relation which a fossil bears to the reflection of light, occasioned partly by the smoothness of the surface or of the aggregated particles of which the surface consists, and partly by its density. Many minerals possess both external and internal lustre, of which the last is the most constant and the most important as a characteristic. With respect to intensity of lustre, the following different degrees may be established.

The *Resplendent* lustre. A mineral which exhibits, even at a distance, a dazzling lustre, is said to be resplendent, as native mercury, and the external surface and fracture of rock-crystal and sulphuret of lead.

Shining. A mineral is said to be shining, when its lustre, though perceptible at a distance, is not so distinctly observed as on a nearer approach; such are sulphate of baryta, most calcareous spar, and pitchstone.

Weakly-shining. This degree of lustre is perceptible only at a short distance, and even then appears rather feeble; it is seen in gray copper, sulphuret of iron, most kinds of quartz, and garnet.

Glimmering. A mineral is said to have this kind of lustre, when only some of the minute aggregated parts of a fossil reflect light; such are glimmering earthy talc, compact sulphuret of lead, and hæmatites.

Dull. A mineral, whose surface is wholly destitute of lustre, is termed dull. Hornstone, chalk, marl, and most earthy minerals, may serve as examples.

The different kinds of lustre, arising from the different degrees of density, are the—

Vitreous or *Glassy* lustre, resembling that of the fracture of glass. This is seen in common quartz, rock-crystal, calcareous spar, and fluor-spar.

The *Waxy* or *Greasy* lustre resembles that of wax. Chloride of silver (or horn-silver) and opal are examples of it.

The *Resinous* lustre resembles that of the fracture of gums or resins; jet amber, and cannel-coal, exhibit this kind of lustre.

The *Pearly* lustre resembles that of mother-of-pearl; it exists but rarely except in minerals that have a lamellar structure. Zeolite and adularia afford examples of it.

The *Silky* lustre is peculiar to minerals having a fibrous structure, as in satin-spar and malachite. It is often accompanied by a changeable play of light called by the French *chatoyant;* of which the cat's-eye and Labrador felspar furnish such beautiful examples.

The *Adamantine* lustre is that of the diamond and corundum.

The *Metallic* lustre is seen in the metals in their metallic state, as in native mercury, native gold, and on the polished surfaces of copper, silver, and steel.

The *Semi-Metallic* lustre is intermediate between the metallic and the vitreous; mica, and sometimes common coal, exhibit it.

The *Pseudo-Metallic* lustre is a species of metallic lustre peculiar to a few minerals, and perceptible only when held in particular directions, as in hypersthene and bronzite.

Colour. Colour is not of much importance as a distinctive character, since there are very few earthy minerals in which it is at all characteristic, the same mineral frequently occurring under every variety of shade, of a great many different colours. The earths in their pure state, are nearly white; and the varieties of colour met with in their combinations arise from the presence of small portions of different metallic oxides as accidental ingredients. In some of the metalliferous ores, however, the internal colour is less variable, and sometimes becomes a good characteristic.

Flexibility and Elasticity. These are properties confined to a few minerals, of which they are therefore highly characteristic. A mineral is said to be *flexible*, which, on being bent, does not recover its former shape. If it returns to its original shape after being bent, it is said to be *elastic*. Mica and talc are thus distinguished from each other, mica being elastic, talc merely flexible.

Double Refraction. Several crystallized minerals, but more particularly a very pellucid variety of calcareous spar, possess the property of doubling the image of objects seen through them in certain directions. This arises from the ray of light, by which the object is seen, being split in its passage through the crystal into two, which make a certain angle with each other, and this effect is probably produced by the form of the component particles of the crystal. Double refraction may be considered rather as a curious property of those minerals that possess it, than as a distinctive character. So far from being characteristic of calcareous spar, in which it is found in the greatest perfection, it is confined to one variety of that mineral, called Iceland spar, and sometimes doubly-refracting spar.

Touch. This is a good distinctive character in a few minerals. Some, when handled, feel smooth or unctuous, others dry and meagre. Fullers' earth, steatite, talc, and plumbago, may be cited as examples of the unctuous chalk and gypsum of the meagre feel.

Taste. This is confined to the saline minerals, which are soluble in water, many of which are distinguishable by their peculiar tastes.

Odour. This is by no means a general character, being found in not more than about twelve kinds of minerals; but of those it is very essential as a characteristic. There is the bituminous odour, in mineral pitch and naphtha, and the sulphureous in native sulphur and sulphuret of antimony, which they give out of themselves. Others exhale peculiar odours on being breathed on or rubbed. We have already spoken of the *argillaceous* odour given out by minerals containing alumina, when breathed on, and of the *fetid* odour of swinestone when rubbed, arising from the presence of sulphuretted hydrogen; other minerals, when rubbed, give out the *sulphureous* odour, as iron pyrites, and the *alliaceous*, or odour of garlic, as arsenical pyrites, and white arsenical cobalt, or the *empyreumatic* odour, as coal and quartz.

Streak, or Powder. When a mineral is scratched with a knife, it yields a powder sometimes of the same colour as itself, sometimes different. This is called the colour of the streak, and is in many cases a good distinctive character, particularly of some of the metallic minerals, which in other respects possess considerable resemblance to one another. Specular iron, and micaceous iron, give a streak of a crimson red; black slate a gray, and hornblende a greenish-gray streak.

Stain. By the stain is meant the colour left upon paper by drawing a mineral along its surface. Thus the stain left upon paper by plumbago is lead-coloured, that of red ochre and red scaly iron-ore red.

Adhesion to the Tongue. This property arises from the affinity of the mineral for moisture, and is very characteristic of the few that possess it. Lithomarge and chalk are examples.

Magnetism. This character is confined to the metals iron, nickel, and cobalt, particularly the first, the ores of which differ considerably in their powers of attraction, some attracting iron-filings, others only affecting a magnetized needle; some attract both its poles, others attract one pole and repel the other, and are then said to be magnetic with polarity. Most varieties of sulphuret of iron become magnetic after having been roasted to drive off the sulphur, but one kind, thence called magnetic pyrites, affects the needle in its natural state.

Electricity. This, like double refraction, must be considered rather as a curious property of the minerals in which it is found, than as a distinctive character of much importance. Some minerals, more particularly the tourmaline, acquire electric properties on being heated, the existence of which is ascertained by means of an instrument called an electrometer. This consists of a light brass needle *a b*, (fig. 19,) having a brass ball at either end, and traversing easily on a pivot in the centre of the support *c* (which may also serve as a support to the magnetic needle); *d* is a plate of glass, by means of which the instrument is insulated, glass being a non-conductor of electricity.

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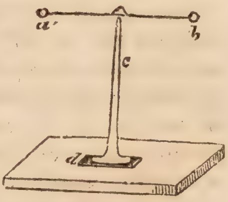

There are two kinds of electricity, positive and negative. The first is produced by exciting smooth glass by friction, the latter by exciting sealing-wax or resins. When two substances possess the same kind of electricity, whether positive or negative, they repel each other; but when they are in different states of electricity, they attract each other. In order to ascertain the kind of electricity possesed by a mineral, we must first bring the electrometer into a known state of electricity. This may be done in the following manner; a stick of glass being excited, we place a finger on *c*, the metallic base of the instrument, and then bring the excited glass near one of the balls of the needle, holding it there for a few seconds until the instrument is sufficiently electrified. The finger is first to be withdrawn, and then the glass stick. The instrument will now have acquired a negative electricity, and should the excited body presented to it be positively electrified, it will attract the needle, and repel it if negatively electrified. On heating a crystal of tourmaline, it will be found to have acquired positive electricity at one end, and negative at the other.

PHOSPHORESCENCE. This is likewise a character confined to a very few minerals, nor does it seem essential to those that possess it. It is best exhibited in fluor-spar; but there are some varieties of that mineral which are not phosphorescent. Phosphorescence may be produced either by heat, as in fluor-spar, or by friction, as in some varieties of blende, and in quartz. The best mode of exhibiting phosphorescence by heat is by reducing the mineral to powder, and sprinkling the powder on a shovel made nearly red-hot.

SPECIFIC GRAVITY. This is a very important character which is of itself sufficient to distinguish different substances bearing in other respects a close resemblance to each other. Equal bulks of different bodies differ in weight; they are of different densities, or contain different quantities, of ponderable matter in the same space; and by specific gravity is meant the weight of a given bulk of any body, compared with an equal bulk of another body. If a cubic foot of water weigh 1000 ounces, a cubic foot of iron 7000 ounces, and a cubic foot of stone 3500 ounces, the iron will be just twice the specific gravity of the stone, and the specific gravities of these two bodies are to that of water in the ratio of 7 to 1 and 3½ (or 3·5) to 1.

The weight of distilled water (a cubic foot of which at the temperature of 40° Fahrenheit, weighs 1000 ounces,) has, for convenience, been assumed as the standard of comparison; and by comparing the weight of given bulks of different bodies with the weight of an equal bulk of water, considered as unity, we obtain a series of numbers representing the comparative density, or specific gravity.

The specific gravity of such bodies as are lighter than water, are expressed in decimals; and that of bodies heavier than water by integers and decimals; thus, in the example above given, a block of stone weighing 3500 ounces to the cubic foot, would be 3½ times heavier than water, and its specific gravity would be expressed by the decimal 3·500, or its equivalent decimal, 3·5.

If a body be weighed in air, in the common manner, and then being suspended by fine thread or hair to one end of a scale-beam, be weighed immersed in water, it will appear to have lost part of its weight. This loss arises from the support which the body receives from the upward pressure of the water, (fluids pressing equally in all directions,) and it is equal to the weight of a quantity of water of the same bulk as the body immersed. The weight of a body in air is called its absolute weight, and its loss, when weighed in water, gives the absolute weight of an equal bulk of water. Here, then, are the absolute weights of two bodies of equal bulk; and the proportion which these bear to one another, taking the weight of water as unity, is the proportion of their specific gravities.

To find, therefore, the specific gravity of a body heavier than water, weigh it both in water, and out of water. Then say,

As the loss of weight in water
Is to the absolute weight,
So is the specific gravity of water
To the specific gravity of the body.

Thus, if a piece of stone weigh 10lbs. in air, but in water only $6\frac{3}{4}$lbs. then $10 - 6{\cdot}75 = 3{\cdot}25$, the weight lost in water, and $3{\cdot}25 : 10 :: 1 : 3{\cdot}077$, the specific gravity of the stone.

To find the specific gravity of a body lighter than water, annex to it a piece of some other body heavier than water, so that the mass compounded of the two may sink: weigh the denser body and the compound mass separately, both in water and out of it. Then find how much each loses in water, by subtracting its weight in water from its weight in air, and subtract the less of these remainders from the greater. Then say,

As the last remainder
Is to the weight of the light body in air,
So is the specific gravity of water
To the specific gravity of the body.

If, for example, a piece of wood weigh 15 lbs. in air, and a piece of copper affixed to it to make it sink, weigh 18 lbs. in air, and 16 lbs. in water, the compound mass weighing 6 lbs. in water, then

$18 - 16 = 2$ weight lost by the copper in water,

$15 + 18 - 6 = 27$ weight lost by the compound mass in water.

$27 - 2 = 25$,

and $25 : 15 :: 1 : {\cdot}6$, the specific gravity of the wood.

To find the specific gravity of any sort of fluid, weigh a piece of any substance of known specific gravity, both in the fluid and out of it, and find the loss of weight by taking the difference of the two. Then say,

As the absolute weight
Is to the loss of weight,
So is the specific gravity of the solid
To the specific gravity of the fluid.

A piece of cast iron, for example, weighed 34·61 ounces in a fluid, and 40 ounces out of it. What was the specific gravity of the fluid ?

40 — 34·61 = 5·39, weight lost by the iron in the fluid,

Then 5·39 : 40 : : 1 : 7·422, specific gravity of the iron, and 40 : 5·39 : : 7·422 : 1, the specific gravity of the fluid.

The specific gravity of solids and fluids may also be taken by means of a small bottle, called a specific-gravity-bottle, of known weight, and capable of containing a known weight of water. With this, the specific gravity of a fluid may be found merely by filling the bottle and weighing it; that of a solid may be found by filling the bottle with water, and then putting in a known weight of the solid in fragments, which will of course displace an equal bulk of water, the weight of which is to be ascertained by weighing the bottle after having wiped its outer surface quite dry.

Different specimens of the same kind of mineral vary a little in specific gravity, from the accidental mixture of foreign ingredients, or from their component parts being more or less intimately combined. Crystals, which are the most pure form of a mineral, exhibit the least difference in this respect, and those that are massive the greatest, particularly the ores of metals; but a sort of standard may be established for each kind of mineral by taking the mean of a number of specimens of as great purity as can be procured, and this mean specific gravity is of considerable value as a distinctive character.

CHAPTER VII.

Chemical characters of minerals.—The blowpipe, and blowpipe apparatus—mode of using them.—Qualitative analysis.—Mode of proceeding to discover by chemical tests the electro-negative portion of a mineral—its electro-positive portion or base.

One of the greatest difficulties to be encountered by the student in discovering the name of a mineral by means of the external characters, arises from the classification usually adopted in systems of mineralogy, being founded, not on those characters, but on the composition of minerals as deduced from analysis. This is, without doubt, the most scientific mode of classification; but at the same time it ought to be accompanied by an artificial division into classes, orders, and genera, founded on the external, or the pyrognostic characters, or on a combination of the two, in order to enable a person unacquainted with the name and composition of a mineral, to ascertain in what part of the scientific system to look for a description of it.

In the absence of assistance from such an artificial arrangement, serving as an index to the philosophical system, the student's only resource, after observing and noting down the external characters of the specimen, the name of which he wishes to discover, is to wade through the volume which he consults, until he find a species of mineral agreeing with his own description of the specimen under examination. The only work known to us in which the external characters are made the basis of any such artificial classification, is Bakewell's Introduction to Mineralogy, in which a tabular view is given of the most important earthy minerals, grouped according to their hardness and specific gravity. Aikin's Manual, a work now out of print, contains, in like manner, a table of their pyrognostic characters, or habitudes before the blowpipe; and in Griffin's Treatise on the Use of the Blowpipe, these two modes of classification are combined in a system founded on the most important physical and chemical characters. This is a cheap and useful little work, which, as a companion to the blowpipe, ought to be in the hands of every one desirous of acquiring a knowledge of mineralogy. Under its guidance, we mastered the use of the blowpipe, without the aid of other instruction, and made, in a short time, more progress in identifying minerals than we had made in years while relying on other sources of information; and we have no hesitation in declaring that with this little volume before him, and the blowpipe in his hand, the student possessed of only moderate perseverance, will have no difficulty in satisfying himself of the name of any mineral which he may meet with.

In that work will be found a history of the application of the blowpipe to chemical investigation, together with minute directions for manipulation. Our limits will not permit us to enter so much into detail; neither shall we discuss the relative merits of Gahn's, or Tenant's or Wollaston's blowpipe, or of any of those other modifications of the form of the common instrument which bear the names of the philosophers who have attempted to improve it. One reason for our silence on this point is, that we have had no experience in the use of any blowpipes except the common instrument used by working jewellers, and that called Cronsted's, which has a bulb near its smaller end, designed to obviate the inconvenience arising from the condensed moisture of the breath, and after a few trials, we gave the preference to the common instrument, which we have since exclusively used.*

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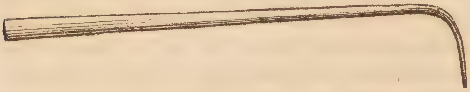
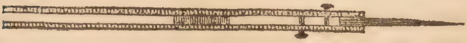


The student should be provided with two blowpipes of the common form (figure 20;) one with a very fine orifice, for fusing earthy minerals, and for reducing ores to the metallic state; the other with an orifice somewhat larger, for roasting ores and oxidizing metals in the outer flame. Besides these, the following apparatus will be required for ascertaining the chemical characters of minerals, either by the dry or the humid process; some of the apparatus being used in the one, some in the other, and some being equally useful for both.

Fig. 21 is a pair of forceps, of brass, tipped with platinum, for holding small fragments of earthy minerals in the blowpipe flame.

21



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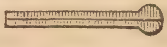

Another pair of forceps will be required, having at the extremity a pair of cups of platinum, (fig. 22,) for holding minerals which decrepitate on the application of heat, and which would fly about and be lost, unless confined until heated to redness, when decrepitation ceases. As a substitute for these latter forceps, a small piece of platinum foil may be used, in which the mineral can be folded up, and thus preserved during decrepitation. Platinum foil, cut into narrow strips about two inches long, and half an inch broad, is also useful for supporting some minerals when treated with fluxes; platinum being so bad a conductor of heat, that one extremity of a piece of foil, of the size above-mentioned, may be held in the fingers without inconvenience, while the other end is heated to whiteness in the blowpipe flame.

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* The blowpipe known by the name of Black's, which has now become very common, and costs from 1*s*. 6*d*. to 2*s*. 6*d*., is perhaps a preferable instrument.

Platinum wire, cut into lengths of two or three inches, and bent into a small hook at one end, is very convenient as a support for a mineral to be heated with a flux. The end of the wire is to be moistened in order to make the flux adhere, which is then fused into a globule with which the *assay*, or mineral to be examined, is mixed by bringing it into contact with the fused globule while still soft, or by moistening its surface when cold. The two substances are then fused together, and an insulated mass is thus obtained, which is easily examined, and which may be detached by gently tapping the wire while hot. Another mode of operating, is by mixing the flux in a small mortar with the mineral previously reduced to a fine powder, and then fusing them together. This wire is the most convenient support in those cases where the circumstances to be observed, are the changes of colour produced by fusion with borax, soda, or microcosmic salt.

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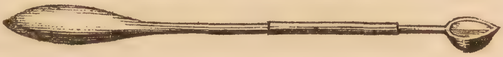

Fig. 23 is a small spoon, the bowl of which is of platinum, having a short shank of the same metal soldered to a longer shank of silver, with a wooden handle. This is a support for earthy minerals, and for such ores as are not reducible to the metallic state without fluxes. It is more easily managed by beginners, than the foil or the wire; but as these abstract less of the heat from the assay, they are preferred by adepts in blowpipe manipulations. To them the chief use of the spoon is for fusing a mineral with soda, though, even for that purpose, some prefer charcoal as a support. Minerals in the metallic state, or which are reducible to the metallic state without fluxes, should never be fused on supports of platinum, as they form alloys with it. Minerals containing sulphur and chlorine likewise injure the platinum. For such minerals, charcoal is the proper support. The best kind of charcoal is that made from the wood of the alder. It should be straight, and free from knots, and should be cut with a fine-toothed saw into strips from four to six inches long. A small hollow is to be made at one end of the charcoal with the point of a knife, or other convenient instrument, and in this hollow the assay is to be placed, in order to prevent its being carried off the charcoal by the blast; and the blowpipe flame is then to be directed upon it. Charcoal that is liable to crack should be gently heated before the assay is applied, in order to prevent burning fragments of it from flying about, thus endangering the eyes of the experimenter, as well as causing the loss of the mineral to be operated upon.*

Charcoal is used as a support for the fusion of the metallic oxides, because it facilitates their reduction by the abstraction of oxygen during its combustion. It is likewise used as a support for compounds of the metals with sulphur, arsenic, and chlorine. Plates of mica are sometimes used as supports, when in roasting ores, it is desirable to avoid the reducing effects of the charcoal.

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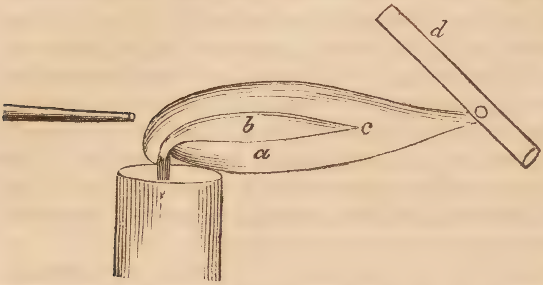

Glass tubes of several kinds will be required for various purposes, both in experiments by the blowpipe and by the humid process. Fig. 24, *d*, is a tube two or three inches long, one-eighth of an inch in diameter, and open at each end, for the purpose of heating minerals which volatilize at a low temperature. The assay is placed at one end, and heated by the blowpipe flame, when volatile matter not permanently gaseous will condense in the upper part of the tube; but a tube open at one end, and blown into a bulb at the other, (fig. 25,) is more commonly used for this purpose, as well as for heating minerals which decrepitate, and for ascertaining the presence of water in them. In this form it is called a matrass, and is very useful for effecting solutions on a small scale, with acids, when the application of heat is necessary.

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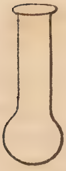

Supports of pipe-clay are sometimes used for exhibiting the colours produced by the fusion of borax and the other fluxes with different metals. They may be made in two ways. Either the clay may be beaten out into very thin plates between sheets of paper, the clay and paper being then cut together into pieces two or three inches long and a quarter of an inch wide, or small bowls or cups of clay may be prepared in the following manner: A piece of brass, one-twentieth of an inch thick, is to be pierced with several circular holes, not quite a quarter of an inch in diameter. It is then to be placed on paper, and the holes are to be filled with moist pipe-clay, worked to the consistency of dough. The superfluous clay being removed, the brass mould with the paper under it is to be placed in the palm of the left hand, while with a finger of the other the clay in the holes is to be pressed so as to give it a concave form. These cups, as well as the strips of clay before mentioned, having been slowly dried, are to be hardened in the fire in a small crucible or the bowl of a tobacco-pipe. In using one of these cups, it may either be held in the inner flame of the blowpipe with a pair of forceps, or it may be cemented to a thin strip of glass, (fig. 26,) with silicated potassa, for use in the outer flame, or it may be cemented with clay to a thin handle of pipe-clay, and then burned, thus forming a small earthen spoon, which, being white, exhibits, to great advantage, the characteristic colours produced by the metals with fluxes.

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* Small boxes, fitted up with blowpipe apparatus, and some of the most useful chemical tests, are now sold at a cheap rate by the Messrs. Griffin of Glasgow, and by their agents in most of the large towns of Great Britain. These boxes are furnished with charcoal, sawn into small pieces, with tin holders, in which to fix them, and an instrument for boring a neat circular cavity in the charcoal.

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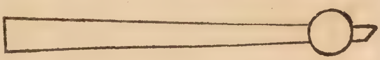

A small mineralogical hammer, broad at one end, and sharp at the other, will be wanted for chipping off fragments of minerals for examination, and for ascertaining the malleability of a metallic globule after fusion, by flattening it on a plate of steel, called a watchmaker's anvil. This hammer and anvil may likewise be used for crushing ores both before and after they have been roasted, the mineral to be crushed being wrapped up in paper to prevent its dispersion. This process, however, is best effected by means of a steel mortar, (fig. 27,) so contrived that a mineral may be broken into small fragments, without any of it being lost. A small pestle and mortar of agate will also be required for reducing a mineral to fine powder for operations with the blowpipe, or acids. Several small files will be useful for the purpose of cutting glass tubes, and for filing the globules obtained from the fusion of ores, in order to ascertain if they possess the metallic lustre. A knife is also indispensable for trying the hardness and sectility of minerals. Knives for the use of mineralogists are made to contain also a magnet and a file. The magnetic needle and electrometer have already been described. A lens must not be omitted, for examining the structure of a mineral both before and after it has been operated upon by heat. A pair of strong cutting pliers, for breaking off portions of minerals, will be found very useful, as also a pair of brass forceps, for taking up small particles of a mineral to be tried, and for handling globules of reduced metal while hot. To these we may add a small wire bent into

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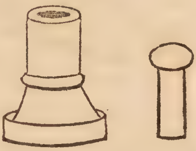

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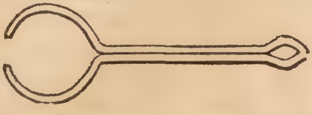

the annexed shape, (fig. 28,) for holding a watch-glass over the flame of a lamp.

We have already spoken of the open glass tube and matrass. Some of the following apparatus of glass will occasionally be used for operations with the blowpipe, but more frequently when solutions are effected with acids. Large watch-glasses, or the lower part of an oil-flask, are useful for submitting small portions of a mineral to the action of acids, and for evaporating solutions; *a a* (fig. 29) are test-tubes, in which solutions of minerals are to be tried with different tests or reagents; *b* is the stand for holding them, to which may be attached an apparatus of wire, *d*, for supporting a watch-glass over the flame of a spirit-lamp, *c*. Two or three dozen of these tubes should be provided, of different sizes. The largest need not be more than half an inch in diameter, and four or five inches long. They should have a lip in the brim for the convenience of pouring out fluids.

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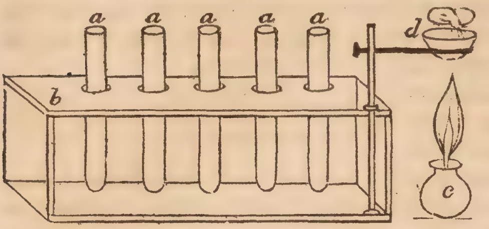

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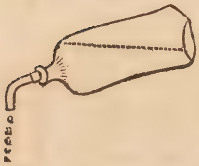

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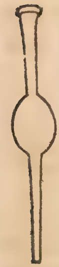

Figures 30, 31, are dropping-tubes, of different kinds. That represented in fig. 30 was the invention of Dr. Wollaston, and consists of a glass tube, with a fine orifice bent at a right angle about an inch from the orifice, and passing through a cork fitted in the neck of a bottle, which is to be about half full of water. The warmth of the hand when the bottle is held in it, dilates the air in the bottle, and slowly expels the water. A continuous jet may be produced by forcing air from the mouth into a bottle fitted with a perforated cork, in which is fixed a glass tube with a fine orifice, and then inverting the bottle. When there is no objection to employment of warm water in the washing of precipitates, the necessary pressure on the water may be produced by heating the bottle over the flame of a spirit lamp and then inverting it. In this case the bottle must be of thin glass, like an oil-flask, which answers very well for the purpose. Another dropping-tube (fig. 31) consists of a narrow glass tube about six inches long, with a bulb about an inch in diameter blown out near the middle, and drawn out at the other extremity into a capillary orifice. This end being immersed in water, the bulb is filled by the action of the mouth on the upper extremity. The water is then prevented from escaping, by closing this orifice with the finger, on the removal of which, the water falls out in drops. These dropping-tubes are used for washing precipitates on filters, and in experiments with the blowpipe are frequently used for separating small fragments of charcoal that have become mixed with particles of reduced metal. A tray will be necessary to catch the assay when it falls from the support. This should be made of tinned iron; it should be about two feet long, and eighteen inches wide, and should be turned up one inch and a half at the edges. It should be lined with white paper, and, to prevent dubious results from the mixture of different substances, should be cleaned every time an experiment is commenced with a fresh mineral.

With respect to the flame employed, that of a candle—an ordinary mould or wax candle—with rather a large wick, is sufficient for the fusion of minerals that are to be held in the forceps, or tried with fluxes on the platinum wire or foil, or in the clay cups. When charcoal is employed as the support, there is this disadvantage attending the use of the candle—that the heat radiating from the charcoal is apt to melt the tallow or wax, and to make it *gutter*, or burn away too fast.* In that case, a lamp made of tinned iron is the most convenient; it may be fed with oil, tallow, or hog's lard. The flame of a spirit-lamp gives a strong heat free from smoke, the only objection to it being the increased expense attending the employment of alcohol as a combustible. When a lamp is used, the wick should be parted in the middle, in order to expose as great a surface as possible to the flame.

The great art in the use of the blowpipe consists in maintaining a continuous, equable stream of air so long as the experiment requires it. To effect this, the blast must not proceed directly from the lungs, but the cheeks must be inflated, and by their compression the air must be forced through the blowpipe, respiration being maintained in the mean time by breathing through the nostrils; this, though rather difficult at first, will become easy after a little practice. The beginner should first learn to breathe through the nostrils, keeping the mouth shut. Let him then learn to distend the cheeks with the air thus inspired, and to make several respirations, without suffering any air to escape from his mouth: when able to accomplish this, let him take a blowpipe between his lips, and having filled his mouth with air, let him expel it gently through the tube by the action of the muscles of the cheeks, while he breathes through the nostrils. To this end the tongue must be applied to the palate, so as to interrupt the communication between the mouth and the passage from the nostrils. As the supply of air in the mouth diminishes, it is to be renewed by withdrawing the tongue from the palate, and again replacing it, as in pronouncing the word *tut.*

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* This objection is in a great measure obviated by the use of small pieces of charcoal, fixed in a tin holder, as described in the last note.

It will be advisable to practise the keeping up of a stream of air in this manner with the blowpipe alone, without applying it to a flame, and having become tolerably expert, the learner may then proceed to try to keep up a steady flame, without attempting to direct it on any object, and when he can do this with facility, he may proceed to the oxidation of metals, the reduction of ores, and the fusion of some of the most fusible earthy minerals. Let him commence with the flame of the candle rather shortly snuffed, the wick being bent in the direction of the intended blast. The orifice of the blowpipe is to be held just above the bent wick, and the air gently expressed through it along the horizontal part of the wick, without touching it. The lamp or candle should be placed at such a height, that both elbows of the operator may rest upon the table while he is using the blowpipe, and the further from the mouth the instrument is held the more steady will it be.

The cone of flame produced by the blast will be found to consist of two portions—an outer and yellow flame, (*a*, fig. 24,) and an inner and blue flame, *b*. Oxidation is best effected at an incipient red heat, the substance to be operated upon being held at the extreme point of the yellow flame, where the gases derived from the decomposition of the combustible matter are burning in immediate contact with the air, and are consequently highly charged with oxygen. Reduction or deoxidation is best effected at the point *c*, just beyond the extremity of the blue cone, where imperfect combustion is going on, and where the flame, requiring a further supply of oxygen, takes it from the metallic oxide acted upon. For this operation, a blow pipe with a small orifice is to be used, and the assay must be kept quite surrounded with flame. A ragged irregular flame shows that the orifice is not round and smooth, and a cavity in the flame shows that the orifice is too large. The learner ought to begin operating upon substances that are easy of reduction, such as bismuth, sulphate of copper, and the carbonate, sulphuret, and red oxide of lead. He may then proceed to the reduction of sulphuret and arseniate of copper, and when he can keep a small grain of tin in a complete state of fusion, so as to preserve its metallic brilliancy, he may consider himself an expert operator. This affords a very good criterion for ascertaining the point at which the flame becomes an oxidating, instead of a reducing flame, for at that point the globule of tin becomes coated with a white crust of oxide.

The small fragment of a mineral submitted to examination by the blowpipe is called the Assay, and with respect to size, it must be observed, that, except in the case of the most fusible substances, the beginner ought not to attempt to operate upon a piece much larger than a grain of mustard-seed. With respect to figure, the assay ought, if possible, to be chipped off in the shape of a small scale, with a sharp edge or point, particularly in the case of minerals that are difficult of fusion, because these fine points or edges are more easily acted upon than a thicker piece, and accordingly as the point or edge becomes rounded, or retains its sharpness, it may be considered fusible or infusible; in order to ascertain this, it is sometimes necessary to examine the assay with a lens. The earthy minerals which are fused with the greatest ease are hornblende and felspar, particularly vitreous felspar.

The operation termed roasting, or calcining, consists in submitting the metallic sulphurets, arseniurets, and other substances containing volatile matter, to a low red heat; the support used in such cases must be either charcoal, the glass matrass, the open tube, or a plate of mica. Unless the roasting be properly performed, so as to expel all the sulphur or other volatile matter, no attempt to reduce the ore, either with or without fluxes, will be attended with any satisfactory result.

Fluxes are substances added to metallic ores, or other minerals, in order to promote their fusion, and their action is either chemical or mechanical. In some cases, the superior affinity of the alkaline or earthy base employed as a flux, abstracts from a metallic oxide the acid combined with it which prevents its reduction. In other cases, the reduction is effected by fusing oxides with inflammable bodies, which deprive them of their oxygen, by combining with it in combustion. The flux sometimes acts mechanically, when the mineral under examination would, on its reduction, be divided into minute particles, not easily collected. By mixing it with a substance easily fusible, a medium is obtained, through which these particles can readily subside. They are thus prevented from being dispersed, and are collected together till they run into a globule, or *prill.*

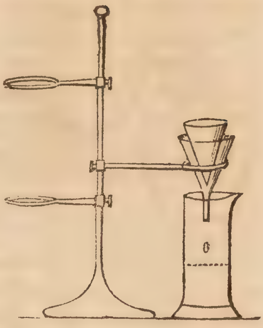
The fluxes of most general utility in blowpipe operations are borate of soda, or borax, carbonate of soda, and microcosmic salt; these must be procured in a state of perfect purity, and kept pulverized in small phials. When borax is first submitted to the blowpipe flame, it becomes white and opaque, and intumesces considerably, on account of the water it contains, but on this being expelled, it fuses into a colourless globule. When a mineral is treated with this flux, the characteristics to be observed are, its degree of fusibility, and whether this takes place quickly or slowly, and whether with or without effervescence, also the colour of the glass, and the alterations which take place in its transparency. The use of carbonate of soda as a flux is twofold—first, to ascertain the fusibility of the earthy minerals, and secondly, to reduce the metallic oxides.

When soda is used with an assay on charcoal, it is very apt to be absorbed by the support, but a continuance of the heat causes it again to rise to the surface of the charcoal, or the absorption may be prevented, by adding the soda in very small quantities. Some minerals are fusible with soda, only when reduced to powder, others combine with small portions of it, fuse with difficulty on the addition of more, and become quite infusible if a large quantity be added. In the examination of a mineral with soda, it ought, therefore, to be tried with different proportions of this flux, noting the effects produced by the use of each successive proportion.

Microcosmic salt, or salt of phosphorus and ammonia, intumesces considerably on exposure to the flame of the blowpipe, and boils until the water and ammonia are dissipated; it then fuses quietly into a clear globule, which continues fluid much longer than that produced by the fusion of borax, for which reason the matter to be examined can be more conveniently added. It is used for the examination of metallic minerals, with which it affords highly characteristic indications in the colour and transparency of the fused mass.

In order to discover the names of minerals with which he is unacquainted, the student may either have recourse to the little work before-mentioned, in which they are classed according to their pyrognostic characters, or if the system of mineralogy which he consults be founded on their chemical composition, he may, by means of a qualitative analysis, determine their principal constituents, and their consequent place in such a system. It will, moreover, be found advantageous in conducting such investigations that in all cases the results obtained by the pyrognostic examination of any substance should be confronted with those obtained by submitting another portion of it to the action of tests after being brought into a state of solution. This may be done by means of the watch-glass and tube apparatus (fig. 29). The solution of the saline minerals in water, and of those that are soluble in acids, is easily effected. Compounds insoluble in acids must be reduced to fine powder, and fused with carbonate of potassa, or carbonate of soda. This fusion may be accomplished with the blowpipe, on platinum foil, or in the platinum spoon. The fused mass will then be soluble in water, and portions of the solution being poured into several small tubes, may be tested with different reagents. Precipitation takes place when the reagent forms, with any of the earths or metals held in solution, a compound insoluble, or sparingly soluble, in the liquid in which they had been dissolved. The colours of the precipitates, and their degree of solubility in hot or cold water, or in acids, afford characteristics by which the different ingredients may be discriminated. Sometimes no precipitate is produced, but the colour of the solution is changed. In other cases, a small quantity of the reagent produces a precipitate which a larger quantity redissolves.

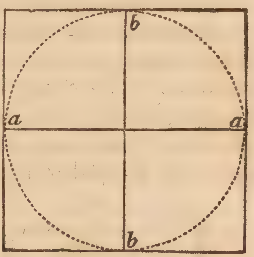
32



It will frequently be necessary, in conducting a qualitative analysis of this kind, to separate a precipitate by filtration, in order that the supernatant liquor may be tested for other substances remaining in solution. Filtration is performed thus: a piece of filtering paper, rather bibulous, and free from size, lime, and other impurities, is folded so as to fit a small glass funnel (fig. 32.) The liquid with the precipitate is poured into the paper, the funnel being placed on a support over a small glass jar. The liquid will then soak through the pores of the filter, leaving the solid matter behind. The precipitate is to be washed on the filter, by repeatedly pouring distilled water upon it until the water which passes through the paper ceases to have any action upon test-papers stained with litmus or turmeric.

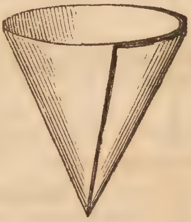
The filtering-paper is to be folded in the following manner, in order to make it fit the funnel. Double a square piece in half, in the direction *a a* (fig. 33). Fold it again, in the direction *b b;* cut off the corners, as shown by the dotted line, and then let the folded paper be opened by thrusting the finger into it, so that the three folds of the paper may be on the one side, and one on the other. A cup will thus be formed (fig. 34), into which, after it is placed in the funnel, the liquor may be poured.*

33



We have spoken of washing the precipitate with distilled water. The same should be used for making aqueous solutions, and for diluting acids in all analytical operations. The reason of this is, that spring water is never perfectly pure, but always contains some salts or earths in solution, which would yield a precipitate with some of the reagents, and give rise to erroneous conclusions. When heat is applied to water, in which saline and earthy matter is dissolved, the water rises in the form of vapour, leaving the salt or earth behind, and, on condensing this vapour, the water is obtained in a state of purity.

34



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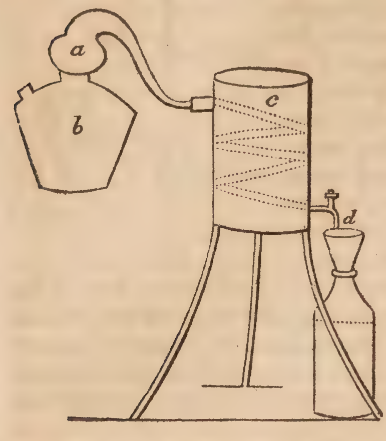
* Messrs. Griffin, of Glasgow, sell filtering-paper cut by a machine into a circular form, and of various diameters; also test-papers, cut into small strips and stitched together in books. These gentlemen are trying as a commercial experiment to create a demand for chemical apparatus, by diminishing the price of it.

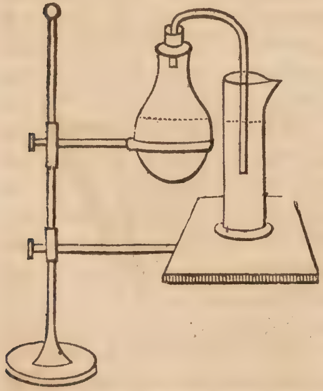
This is the process of distillation, which is conducted by means of the apparatus represented in fig. 35. A head of tinned iron *a*, fitted to the vessel *b*, which contains the water to be distilled, is connected to a worm *c*, passing through a vessel which is filled with cold water, in order to promote the condensation of the vapour, which trickles as it is condensed, through the stop-cock at *d*, into a vessel placed to receive it. This process should be conducted very slowly, in order to obtain the water in a state of perfect purity; for, should ebullition be allowed to take place, some of the foreign matter would rise, mechanically suspended in the vapour, and would be carried over with it. When distilled water cannot be procured, rain water, collected as it falls from the atmosphere, at a distance from any buildings may be substituted for it.

35



A current of sulphuretted hydrogen gas is a reagent of great importance for separating different metals contained in the same solution. We shall therefore describe the mode of preparing it. Sulphuretted hydrogen may be obtained either from proto-sulphuret of antimony and muriatic acid, or from proto-sulphuret of iron and diluted muriatic or sulphuric acid. In a glass flask, (fig. 36,) fitted with a cork having a bent glass tube passing through it, let sulphuret of antimony be heated by means of a lamp, with four or five times its weight of strong muriatic acid. An interchange takes place between the elements of the substances present, the composition of which is as follows. Aqueous muriatic acid consists of muriatic acid gas and water. The elements of water are, oxygen and hydrogen; of muriatic acid, hydrogen and chlorine. Either the water of the acid, or the acid itself, is decomposed.

36



On the first supposition, the oxygen of the water unites with the antimony, producing the protoxide of that metal; and oxide of antimony, combining with the acid, forms muriate of antimony. On the second supposition, the chlorine of the acid forms a chloride with the antimony, and in both cases hydrogen is liberated, either from the water or the acid, which, uniting with the sulphur of the sulphuret, produces sulphuretted hydrogen. Sulphuretted hydrogen may also be procured from protosulphuret of iron, and sulphuric or muriatic acid diluted with three or four times its weight of water. In this case, the water is decomposed; its hydrogen unites with the sulphur of the sulphuret, and sulphate or muriate of antimony remains in solution. In this mode of preparing sulphuretted hydrogen, the application of heat is unnecessary.

Protosulphuret of iron may be obtained by igniting common iron pyrites, which is a deutosulphuret, so as to expel one proportion of sulphur, or it may be formed by mixing two parts of iron filings and rather more than one of sulphur, and exposing them to a low red heat, excluding, during the process, access of air as much as possible.

Bars or cylinders of iron, copper, zinc, and tin will be required for precipitating different metals in the metallic state from their solutions, and some paper should be provided, stained with infusions of litmus and turmeric, as tests of the presence of acids and alkalis. The blue colour of the litmus paper is reddened by acids, and restored by alkalis, and the yellow colour of turmeric paper is changed by alkalis to reddish brown.

The reagents necessary to be procured will be the following:—

Acid, muriatic,
—— nitric,
—— sulphuric,
—— tartaric,
Alcohol,
Muriate of ammonia,
Chloride of platinum,
Prussiate of potassa,
Hydrosulphuret of ammonia,
Liquid sulphuretted hydrogen,
Infusion of galls,
Nitrate of silver,
—— baryta,
—— cobalt,
—— lead,
Caustic potassa,
—— soda,
—— ammonia,
Oxalate of ammonia,
Sulphate of soda,
Subcarbonate of ammonia,
Lime-water,
Distilled water,
Borax,
Subcarbonate of soda,
Double phosphate of soda and ammonia,
Protochloride of tin,
Tin foil.

The following method of conducting a qualitative analysis of minute quantities of mineral substances is recommended by Beudant.*

We have first to *determine to what simple body*, or *to what order of compound a mineral belongs*. The substance to be analyzed will either be one of the only thirteen *simple* bodies that ever occur in nature in an uncombined state, or of that small number of simple or compound bodies which are *negative electrics* with respect to all others; and, consequently, one of the principles of which all substances are composed. These are the bodies whose presence it is necessary to determine, to solve the above question. We have, therefore, to discover whether the substance submitted to analysis, is

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* Traité de Minéralogie.

Antimony,
Arsenic,
Bismuth,
Carbon,
Copper,
Gold,
Iron,
Mercury,
Palladium,
Platinum,
Silver,
Sulphur,
Tellurium,

which are the only simple bodies known to occur in a metallic state; or whether it is an alloy of gold, osmium, or mercury (an hydrarguret,) an antimoniuret, arseniuret, carburet, chloride, iodide, fluoride, seleniuret, sulphuret, or telluriuret, which are the only compounds not containing oxygen. Or lastly, we have to determine whether it is an

Aluminate,
Arseniate,
Arsenite,
Borate,
Carbonate,
Chromite,
Hydrate,
Molybdate,
Nitrate,
Phosphate,
Silicate,
Sulphate,
Columbate,
Titanate,
Tungstate,
Ferrate,
Manganate,

the only ternary and quaternary compounds in which oxygen is present, which have yet been met with in nature. Oxides are excluded from the above list, because it is not easy to determine by these simple experiments whether a given substance is an oxide. *Ferrates* and *manganates* are so named by some mineralogists in which the peroxides of iron and manganese act the part of an acid. They can only be distinguished from the oxides of those metals, and from their combinations as positive electrics, by proving that the substance under examination does not contain any other negative electric, and that it contains a base with which the oxide of iron or manganese is combined.*

A few experiments will suffice to discriminate the simple bodies or different orders of compounds contained in the above list. The mode of proceeding is:

1. To heat the mineral without reagents in a close or open tube, and to examine in different ways the matters given off.

2. To heat it in the same manner with powdered charcoal, or with an acid, which is used sometimes alone, sometimes with peroxide of manganese or copper filings.

3. To fuse it with carbonate of soda, or potassa, in order to produce an alkaline, and consequently a soluble salt, the acid of which is afterwards discovered by different methods.

4. To fuse the mineral, or the precipitates obtained from its solution, with phosphate of soda and ammonia.

The following are the characters exhibited under these modes of treatment by the substances enumerated:

Hydrates. Heated in the closed tube they give off water, which condenses in the cool part of it. We must test this water with litmus and turmeric paper for acids and alkalis; it is not sufficient to determine that a mineral is a hydrate; we must also try if it belongs to any kind of salt, because hydrates have for their bases sometimes simple oxides, sometimes ternary and quaternary compounds of oxygen, &c.

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* The loadstone, or oxidulated iron, is a ferrate of iron, the protoxide of that metal being the base to the peroxide.

Hydrargurets (alloys of mercury), *heated in the closed tube*, give off vapours of mercury, which condense in small metallic globules on the cold part of the glass. The base remains in the tube as a fused mass, at least when not likewise volatile.

Seleniurets, in the closed tube, disengage selenium by the action of heat, which condenses in the form of a red powder; *in the open tube*, or on charcoal, it is converted into a volatile oxide, having a strong odour like that of putrid horseradish. This character is sufficient for the detection of very minute portions of selenium in compounds differing much in their principal constituents.

Arsenic. Lustre, metallic; colour, steel gray, on a fresh fracture. *In the closed tube* is completely volatilized, and deposited in metallic crystals on the cool part of the glass. *In the open tube* yields a strong odour of garlic, and deposits white crystals, which are arsenious acid. Pure arsenic leaves no residue.

Arseniurets. Lustre, metallic. *In the open tube* they have the same characters as arsenic, but leave a residue or give off peculiar odours. *In the closed tube* sublimation of arsenic sometimes occurs.

Arsenic combined with sulphur exhibits the same characters as when pure, but those of sulphur are at the same time observable. When in this case there is no residue, the substance is a simple sulphuret of arsenic; when there is a residue it is a sulpho-arseniuret.

Arsenious acid. In the closed tube is completely volatilized, and deposits small white crystals. *With charcoal*, the alliaceous odour is developed.

Arsenites. In the closed tube, arsenious acid sublimes and a residue remains, at least when the base is metallic. *With charcoal* they yield the alliaceous odour.

Arseniates. In the closed tube no sublimation takes place *with charcoal;* they yield arsenious acid and the odour of garlic. The arseniates are frequently mixed with phosphates, which do not prevent the developement of the above characters. The mode of detecting phosphoric acid will be found under the head of phosphates. The alliaceous odour given out on calcination, either alone or with charcoal, is sufficiently characteristic to indicate the smallest quantity of arsenic in compounds of different kinds.

Antimony. A silver-white metal. In the open tube it gives out copious white vapours *without* the odour of garlic. These condense on the tube in the form of a white powder, which may be volatilized and driven from one part of the tube to another by reheating it. This white powder which is oxide of antimony, is insoluble in nitric acid, but dissolves in muriatic acid, from which it is precipitated white by *water*, and orange-yellow by *sulphuretted hydrogen.*

Antimoniurets have a metallic lustre and behave like antimony, but leave a residue when they cease to give off white fumes. Antimony in these compounds is sometimes the negative, sometimes the positive electric. In either case the reaction is the same, but in the latter the characters of sulphur, arsenic, &c., are exhibited. If there is any residue the mineral contains some other substance.

Oxides of antimony, with charcoal, are reduced to metallic globules, which, heated in contact with the air, are dissipated in white fumes.

Tellurium, a metal of a steel-gray colour. *In the closed tube* it yields a gray sublimate: in the open tube gives out white fumes, which coat the sides of the tube and run into limpid globules; when heated again no residue remains from the operation.

Telluriurets have a metallic lustre, and the same characters as tellurium, but leave a residue.

Osmium. There is but one known compound of this metal, that with iridium. *Calcined* with *nitrate of potassa*, it yields an odour like that of chlorine.

Sulphur yields, while burning, the well-known odour caused by the formation of sulphuric acid. It leaves no residue when pure.

Sulphurets have frequently a metallic lustre. *In the open tube* most of them yield sulphuric acid, like sulphur; they all yield it on being heated mixed with iron filings. Fused with *soda* or *carbonate of soda*, they all produce a substance which on being moistened with acidulated water disengages sulphuretted hydrogen, known by its smell resembling that of rotten eggs. They leave a fusible residue, or give out fumes which indicate the substances with which the sulphur was combined.

Sulphurous acid, gaseous or dissolved in water, having the odour of burning sulphur.

Sulphuric acid, liquid. *Powdered charcoal* saturated with it yields sulphurous acid on being heated.

Sulphates, in the closed tube, often yield the pungent fumes of sulphurous acid. With *charcoal alone*, or *mixed with carbonate of soda*, they produce by fusion a frit which yields sulphuretted hydrogen on being moistened with acidulated water. They give out no sulphurous odour when treated with sulphuric acid.

Carbon in a state of purity is the diamond. It also occurs in black masses, having a pseudo-metallic lustre. *In the open tube* these burn more or less easily; *with nitrate of potassa*, deflagrate at a red heat, and leave a residue of carbonate of potassa.

Carburets. In the mineral kingdom these have a base of hydrogen, and occur gaseous as carburetted hydrogen; liquid as naphtha and petroleum; or solid, and analogous to resinous substances, as asphaltum.

Carbonic acid, a gas without odour, absorbed by the alkalis, and soluble in water, to which it communicates a slightly acid taste, the property of sparkling, and of yielding a precipitate with lime-water, which dissolves with effervescence in acids.

Carbonates dissolve either in hot or cold acids, with an effervescence more or less brisk, produced by a colourless and odourless gas, which is carbonic acid.

Nitrates, soluble or deliquescent; substances which deflagrate with charcoal, and disengage red fumes of nitrous acid, when treated with sulphuric acid after being mixed with copper filings.

Chlorides, with sulphuric acid, give out chlorine, (known by its suffocating odour and greenish-yellow colour,) when previously mixed with pulverized oxide of manganese. *With phosphate of soda and ammonia*, after being fused with oxide of copper, a beautiful blue flame inclining to purple is produced by the volatilization of chloride of copper.

Fluorides. With sulphuric acid some of them yield a pungent gas which corrodes glass. With phosphate of soda and ammonia, previously fused, they all yield the same gas. In the closed tube, some substances heated without reagents produce the same effect, which arises from the presence of fluorine.

Iodides, with sulphuric acid, disengage violet-coloured vapours, having an odour resembling that of chlorine.

Boracic acid communicates to alcohol the property of burning with a green flame.

Borates, borosilicates, with nitric acid, dissolve, leaving a soapy-looking residue which tinges the flame of alcohol green. The residue of borosilicates, fused with carbonate of soda and treated with water, leaves again an insoluble substance, which is silica. The simple borates when thus treated leave no such residue.

The *phosphates, chromates, molybdates, tungstates*, and *columbates*, exhibit none of the preceding characters. Those which occur in nature, with the exception of phosphate of soda, which is soluble, must be fused with carbonate of soda on platinum foil. The result is an alkaline salt soluble in water, to which must be added a little nitric or acetic acid to saturate the excess of carbonated alkali. The nature of the acid in the substance under analysis may then be discovered by treating the solution with different reagents.

Phosphates. The solution yields a white precipitate with nitrate of lead, zinc, and mercury, and a yellow precipitate with nitrate of silver.

The phosphates are often mixed with arseniates, the presence of which is known by the alliaceous odour when heated on charcoal, but which prevent the developement of the above characters. If the arseniate is present in sufficient quantity, the precipitate by nitrate of mercury assumes a slight tint of yellow, that of nitrate of silver turns brown; but in order properly to distinguish the two salts, it is necessary to collect the precipitate by nitrate of lead, to expose it upon charcoal to the reducing flame; the arseniate will then be decomposed, and metallic lead will remain with a globule of the phosphate susceptible of crystallization.

Chromates. The solution gives a yellow precipitate with *nitrate of lead*, and a red precipitate with the nitrates of silver and mercury.

Chromite. The only native chrom*ite* is a compound of the oxides of chromium and iron, generally called chrom*ate* of iron. It is not attacked by carbonate of soda unless in a very strong reducing flame. With nitrate of potassa or of soda the oxide of chrome is converted into chromic acid, and the aqueous solution exhibits the characters of the chromates.

Oxide of chrome, treated like a chromite, produces the same results. In the reducing flame, every substance containing chromium forms with soda a fused mass of a bright green-colour, which changes to yellow in the oxidizing flame.

Molybdates. On the addition of an acid to the solution, they afford a white precipitate of molybdic acid. A bar of tin causes it to change to blue. The precipitate is fusible and volatile, yielding with the double phosphate of soda and ammonia a green glass in the reducing flame.

Tungstates. An excess of acid added to the solution causes a precipitate, white at first, but which is changed to yellow by boiling. The precipitate is infusible, and forms with microcosmic salt a blue glass in the reducing flame.

Columbates. The addition of either nitric or muriatic acid causes a white precipitate, which does not redissolve, (even though the acids may be in excess and the solution dilute,) is infusible, and is rendered, while yet moist, orange by the infusion of gallnuts, and brown by hydrosulphuret of ammonia. With the phosphate of soda and ammonia it yields a colourless glass.

Silicates, or *Silica.* The fusion of these is very difficult, requiring much soda and a long continued heat to produce a soluble substance. The solution yields a precipitate with nitric or muriatic acid when sufficiently concentrated, but not when dilute; but even then precipitation takes place by evaporation. The precipitate is white, does not change colour with any reagent, is infusible, and forms a colourless glass with the double phosphate of soda and ammonia. Many silicates are soluble in acids without fusion with a carbonated alkali, and form a transparent jelly. This jelly is produced by the silicic acid which separates from the substance. All minerals, therefore, which gelatinize with acids are silicates. The silicic acid obtained by either process sometimes contains boracic acid, which may be known by the green flame it imparts to alcohol.

Titanates, oxides of titanium. The result obtained by fusion with a carbonated alkali is insoluble in water, but soluble in muriatic acid. The solution diluted with water is rendered purple by the action of a bar of zinc, and by boiling; or the addition of oxalic acid produces a precipitate, which, in the reducing flame with microcosmic salt, forms a bluish violet glass. When the titanate is not ferruginous, the precipitate occasioned by prussiate of potassa is reddish brown; if iron is present, it will be green.

Aluminates. The fusion with carbonated alkali is incomplete; the product insoluble in water, and often difficult of solution in muriatic acid. No precipitate is produced by evaporation. With ammonia the solution yields a gelatinous precipitate, which redissolves on the addition of potassa. The precipitate becomes of a beautiful blue colour on being heated with nitrate of cobalt.

The Metals which have been mentioned as occurring in a native state, may be known by the following characters:—

Silver. Colour, white; soluble in nitric acid, the solution yielding with muriatic acid, or a chloride, a precipitate, insoluble in acids but soluble in ammonia.

Bismuth. Colour, reddish-white; soluble in nitric acid, the solution yielding a white precipitate with water. Calcination on charcoal, or in a tube, produces an oxide, not volatile, inclining to yellow, which communicates no colour to the flame.

Iron. Colour, well known; soluble in nitric acid. The solution yields a blue precipitate with prussiate of potassa, a black, precipitate with infusion of galls.

Copper. Colour, red; soluble in nitric acid. Solution, bluish-green, giving with the fixed alkalis a blue precipitate, and with ammonia a bluish precipitate, which redissolves in an excess of the precipitant, and forms a beautiful blue solution.

Palladium. Colour, white; soluble in nitric acid, solution red, yielding an olive-coloured precipitate with prussiate of potassa, and a metallic precipitate with protosulphate of iron.

Gold. Colour, yellow; soluble only in nitro-muriatic acid, the solution yielding a purple precipitate with protochloride of tin, and a brown precipitate of metallic gold with protosulphate of iron.

Electrum, a native alloy of gold and silver, the only known *Aururet,* produces the same precipitates with the same reagents; a precipitate of chloride of silver taking place before the purple precipitate produced by protochloride of tin.

Platinum. Colour, dull white, soluble only in nitromuriatic acid, the solution yielding a yellow precipitate with the muriates of potassa and ammonia.

The substances not referrible to any of the preceding are the oxides of tin, bismuth, lead, uranium, cobalt, and copper, the characters of which will be described hereafter.

Having ascertained the nature of the substance acting as the negative electric in a compound body, we have next to *determine the substance constituting its base or electro-positive portion.* In order to accomplish this, it is necessary, in every case, that the mineral should be previously brought into a state of solution.

The Antimoniurets, Arseniurets, Hydrargurets, Seleniurets, Sulphurets, Telluriurets,	Must always be attacked with nitric acid, sometimes with nitromuriatic acid; the solution must be carefully evaporated to dryness, and the residue taken up with water.

The Carbonates will dissolve either in the hot or in the cold, in nitric or muriatic acid.

The Arseniates, Borates, Chlorides, Chromates, Iodides, Molybdates, Phosphates, Fluorides, Sulphates, Columbates, Tungstates,	When insoluble, must be fused with carbonate of soda or potassa, and the result treated with water; the residue is to be dissolved in muriatic acid, the solution evaporated to dryness, and redissolved in water.

The Silicates, Titanates Aluminates,	Must be fused with carbonate of soda or potassa; the resul will dissolve immediately in muriatic acid, is to be evaporated to dryness, and taken up by water.

All substances soluble in water are to be dissolved in that liquid.

Substances of the first Series.

The only bases hitherto known in compounds of this kind, are

Arsenic,
Antimony,
Cadmium,
Manganese,
Cobalt,
Tin,
Molybdenum,
Bismuth,
Silver,
Mercury,
Lead,
Copper,
Iron,
Nickel,
Zinc.

Arsenic, antimony, tellurium, and selenium, in however small quantity they may be present, will have been already discovered by the experiments made to determine the order of compound to which the mineral belonged. We may first proceed to try for cadmium, manganese, and cobalt, so as to render it unnecessary to test for them in solution.

Cadmium. Heated on charcoal it produces a circle of red or orange-yellow powder, however small the quantity of it which the mineral may contain.

Manganese, when fused with carbonate of soda on platinum foil, produces a green substance, which acquires a bluish tint on cooling.

Cobalt, after being roasted with borax in the reducing flame, gives a deep blue glass.

Nitric acid, in acting on the substances now under consideration, reduces them to the state either of an oxide or an acid. The oxides of tin, antimony, and molybdenum, are precipitated as they form, at the bottom of the matrass, and may be distinguished from one another by the following characters:—

Oxide of Tin does not volatilize when heated on charcoal, is reduced with carbonate of soda, and yields a metallic globule which is *malleable* unless, which sometimes happens, it contains oxide of antimony. In that case, the metallic globule gives out white fumes, and becomes malleable when they cease, or is converted into an oxide which surrounds the assay.

Antimonious Acid gives out white fumes on the charcoal, and is reduced with carbonate of soda to a *brittle* metallic globule. This globule, when thoroughly roasted, leaves a malleable button, or a white oxide if it contains tin.

Molybdic Acid. See its characters under *Molybdates.*

Should the mineral acted upon by nitric acid contain sulphur and lead, part of the sulphur will be converted into sulphuric acid, and a precipitate of *sulphate of lead* will be formed. The sulphuric acid of the sulphate may be detected by the characters pointed out under that head, the lead by the precipitate being blackened by sulphuretted hydrogen.

In treating an arseniuret, or a mineral containing arsenic crystals of arsenic acid may form on the cooling of the liquor, or precipitates of arseniates, but the latter will not take place so long as the nitric acid is in excess. The presence of arsenic will have been determined by the preliminary experiments.

In treating a seleniuret, or a mineral containing selenium, we may have crystals of selenic acid. The presence of selenium will also have been determined by the preliminary experiments.

It will sometimes happen, when we employ nitric acid, that a small quantity of yellow metallic matter will remain undissolved. This will consist of particles of gold.

This being premised, we may proceed to the examination of the solution. It will contain

Bismuth; if a drop thrown into a considerable quantity of water, produce an immediate white cloudiness.

Silver; if a drop of muriatic acid, or of a solution of chloride of sodium, produce a white curdy precipitate, soluble in ammonia.

Mercury; if a portion of the liquor, treated with muriatic acid precipitate on a plate of copper a gray powder which acquires by friction a silvery lustre, and is easily volatilized by the application of heat.

Lead; if a drop of sulphuric acid or a solution of a sulphate, added to the same portion of the liquor, form a white precipitate, which blackens on the application of sulphuretted hydrogen.

Iron; if one portion of the liquor into which metallic iron has not been introduced, form a blue precipitate with ferroprussiate of potassa.

Nickel; if the liquor in which a bar of iron has been allowed to remain a sufficient time to separate all the copper, become blue on the addition of ammonia.

Zinc; if one portion treated with caustic potassa, in excess, and filtered, still retain something which forms a white precipitate when carefully saturated with an acid.

We may discover those metals which have the property of forming double compounds. Thus:—

Tungsten and Columbium. These form an immediate precipitate of tungstic and columbic acids.

Platinum, Gold, Iridium. These will not be dissolved by nitric acid, but will be attacked by nitromuriatic acid, and will be precipitated with the mercury by metallic copper.

Rhodium dissolves with difficulty even in nitromuriatic acid; should it be brought into solution, it will be precipitated with the mercury.

Palladium will be precipitated with the mercury, and will yield a metallic precipitate with protosulphate of iron.

Uranium. The solution, treated with carbonate of soda in excess, will yield a precipitate on the addition of an acid. This precipitate, redissolved by the acid, will afford a red-coloured precipitate, with ferroprussiate of potassa.

Cerium, soluble only in nitromuriatic acid, is precipitated white by ferroprussiate of potassa, and also by the alkalis and hydrosulphuret of potassa.

Substances of the other Series.

The solutions of substances of these series may contain nearly all the oxides; but it must be observed, that we do not find, and that it does not appear possible to find in them, gold, plantinum, palladium, rhodium, and iridium, since these bodies are so little liable to oxidization. We never meet with more than a small number of oxides united in the same mineral; but to avoid too much detail, all that can be met with will be supposed to be present in the same solution, viz.:—

Cadmium,
Manganese,
Cobalt,
Chromium,
Lithium,
Ammonia,
Bismuth,
Silver,
Mercury,
Copper,
Nickel,
Iron,
Lead,
Baryta,
Strontia,
Alumina,
Yttria,
Glucina,
Zirconia,
Uranium,
Zinc,
Lime,
Magnesia,
Potassa,
Soda.

We first ascertain by preliminary experiments, as before, whether the mineral contain cadmium, manganese, and cobalt; we determine also when it is not a chromate, whether it contain oxide of chromium, and whether lithia and ammonia are to be found in it.

Oxide of Chromium. The mineral treated with carbonate of soda on platinum foil forms a green substance in the reducing flame, which becomes yellow in the oxidizing flame.

Lithia. The mineral being reduced to powder, and treated with soda on platinum foil, the disengagement of lithia will produce on the metal a yellowish brown stain round the fused mass; on removing the stain with water, it will be found that the metal is corroded.

Ammonia. This alkali is only found in the soluble salts. On mixing these salts with a little caustic potassa or soda, the presence of ammonia is indicated by a sharp and urinous odour.

These preliminary trials having been made, we proceed to the other substances:—

Bismuth may be detected by the addition of water, either to the acid liquor in which the carbonates were dissolved, or to the residue of evaporation which was taken up in water. Silver, mercury, copper, nickel, and iron, may be detected by the reagents before described.

We have now only to attend to other substances, the characters of which we are about to point out.

Oxide of Lead, Baryta, Strontian. A drop of sulphuric acid, or of a sulphate, produces a white precipitate in the solution; that of *Lead* is immediately blackened by the vapour of sulphuretted hydrogen,—that of *Baryta* is not blackened by it, and precipitation takes place, however dilute the solution,—that of *Strontian* is not blackened by the sulphuretted hydrogen, but it does not form in a dilute solution.

After these experiments, ammonia is to be added in excess. The substances then divide into two classes, one of which is *precipitated*, the others remain in *solution*.

Substances precipitated. In the precipitate we are to look for uranium, alumina, glucina, yttria, cerium, and zirconia. The precipitate is to be exposed to the air for some time, and then agitated in water, which is to be divided, while troubled, into four portions. The different substances contained in it may be discriminated in the following manner:—

Uranium is present if carbonate of potassa, dissolved in one portion of the water, take up any of the substances held in suspension, and if the liquid, after being filtered and saturated with an acid, yield a blood-red precipitate with ferroprussiate of potassa.

Yttria and Glucina are present if carbonate of ammonia, dissolved in one portion of the water, take up any of the suspended matter. If the liquid yield a precipitate with caustic soda in excess, after being saturated with an acid, it will be yttria. Glucina so treated yields no precipitate. If, after the separation of the yttria, the supernatant liquor contain any thing, it will be *one or other of those* earths.

Alumina and Glucina. If caustic soda, added to a third portion of the water, take up any thing, these earths will be present:—*Alumina*, if the solution, saturated with an acid, yield a precipitate with carbonate of ammonia in excess; *Glucina*, if no precipitate take place; *either of them*, if the supernatant liquor contain any thing after the separation of the alumina.

Cerium and Zirconia. If, on adding an acid to a fourth portion of the water to dissolve the matter held in suspension, oxalate of ammonia cause a precipitate, these earths will be present:—*Cerium*, if the precipitate become brown by calcination, and give with borax a glass red or deep orange while hot, yellow when cold; *Zirconia*, if the precipitate give out a bright light during calcination, and yield a white opaque glass with borax; *either of them*, if, after being well calcined, an acid dissolve one part of the precipitate and leave another, which is zirconia.

The Ammoniacal Liquor. After having examined, in the above manner, the precipitates produced by caustic ammonia, we proceed to determine the nature of the substances remaining in the solution. It may contain zinc, lime, magnesia, lithia, soda, and potassa, which we test for thus:—

Lime is immediately precipitated by oxalate of ammonia, and the precipitate, after calcination, reddens turmeric paper.

Nickel and Cobalt are sometimes precipitated at the same time, but neither of them change the colour of turmeric paper.

Zinc. If the liquor, being evaporated, and the residue taken up by an acid, the new solution treated with caustic soda in excess, retain any thing which will yield a white precipitate on being cautiously saturated with an acid, it is zinc.

Magnesia is present, if, on evaporating the liquor to dryness, and taking up the residue with an acid, the new solution, treated with hydrosulphuret of potassa and filtered, give a precipitate with soda.

After these trials nothing but lithia, soda, and potassa, can exist in the compound examined. These alkalis are found in the soluble salts or in the silicates. To discover them in the latter it is necessary, if they are not soluble in acids, to fuse them with nitrate of baryta, to pulverize the fused mass, and to digest it in nitric acid. Having by these means, or by direct solution (when practicable) in water, or an acid, obtained a solution *to which none of the three alkalis has been added*, we precipitate all that is susceptible of precipitation by carbonate of ammonia. After filtering the liquid, it is evaporated, and the residue calcined till it ceases to give out vapours. If then there remain any thing in the capsule soluble in water, it will be one of the three alkalis which are distinguished by the following characters:

Lithia. The concentrated solution yields a precipitate with carbonate of soda. The precipitate corrodes platinum in the manner before described.

Potassa. The solution yields a yellow precipitate with chloride of platinum.

Soda exhibits neither of these characters. If the three alkalis be present together, the first and second may be detected by the above process,—as for the soda, it must be converted into a sulphate, evaporated gently, and allowed to form crystals. Its presence may then be known by the efflorescence of its sulphate, which after some days exhibits small white points among the other crystals.

Operations to be followed in more simple cases.

We have supposed, in the preceding analysis, the oxides which are found in different combinations to be all present in the same solution. This has shortened the description, which would otherwise have required a number of divisions for the different cases which might arise, but the problem has thus been rendered more complicated than usual. In fact it is rare to find six or seven bases in the same compound; we seldom meet with more than two or three, and sometimes not more than one. The research thus becomes more easy, since it is not necessary to dissolve the precipitates, and since each drop of the solution indicates if a certain body exist or does not exist in it. We will give some examples. It must first be remarked that uranium, yttria, glucina, cerium, and zirconia, are of rare occurrence, and that there are only certain minerals, and those for the most part having peculiar characters, in which they are found. It follows that, in ordinary cases, after testing by the easy process indicated above for oxide of lead, for baryta and strontia, we have only to determine the presence of lime, alumina, oxide of zinc, magnesia, and the alkalis. Proceeding then with the portion of the solution treated with sulphuric acid, or a soluble sulphate, we may know that it contains:

Lime, if it form a precipitate with oxalate of ammonia.

Alumina, or *Oxide of Zinc*, if, when treated with an excess of soda, it retains any thing in solution which is precipitated when carefully saturated with an acid. *Alumina* is present if the solution, on being supersaturated with an acid, so as to dissolve the precipitate, yield a new white flocculent precipitate at first, which dissolves soon after.

Magnesia may be known by forming a precipitate with soda or potassa, after being treated with a hydrosulphuret of ammonia and filtered.

If the substance under analysis contain none of the metals discovered before the lead, baryta and strontia, the research will be still more simplified. After having treated it with sulphuric acid, or a sulphate, we may immediately detect,

Lime, by oxalate of ammonia;

Magnesia, by soda;

Alumina, by ammonia, which then gives a white flocculent precipitate.

CHAPTER VIII.

MATERIALS COMPOSING THE CRUST OF THE EARTH.

Simple minerals entering into the composition of rocks—quartz—felspar—clinkstone—claystone—mica—talc—chlorite—hornblende—augite—actinolite—hypersthene—diallage—steatite—serpentine—carbonate of lime—carbonate of magnesia—bitterspar—dolomite—sulphate of lime—bitumen—oxide of iron—sulphuret of iron—schorl—chiastolite—garnet.

In treating of the different formations of geology, we shall take them in the ascending order, beginning with the unstratified rocks; granite, one of the principal of these, being the lowest rock met with, and the most generally diffused. We shall then proceed to the stratified rocks, commencing with the most ancient. Since the classification of the unstratified rocks depends on their mineral character, it will be necessary first to make the student acquainted with those simple minerals of which they are composed.

The following list comprehends all that are absolutely necessary to be known by the young geologist. Those which are of most common occurrence, and enter most largely into the composition of rocks, are placed at the head of the list. The last three generally occur sparingly, disseminated through certain rocks, and are only occasionally present in sufficient quantity to be considered as essential ingredients.

Quartz,
Felspar,
Compact Felspar,
Clinkstone,
Claystone,
Mica,
Talc,
Chlorite,
Hornblende.
Augite,
Actinolite,
Hypersthene,
Diallage,
Steatite,
Serpentine,
Carbonate of Lime,
Carbonate of Magnesia,
Bitterspar,
Dolomite,
Sulphate of Lime,
Bitumen,
Oxide of Iron,
Sulphuret of Iron,
Schorl,
Chiastolite,
Garnet.

Quartz.

This mineral is nearly pure silicic acid. It occurs under the following forms;—Compact in veins and quartz rock:—as nodules, in amygdaloidal rocks;—as rolled masses in conglomerates;—as rounded grains in sandstones, some kinds of quartz rock, and coarse clay-slate;—crystallized in the substance of granite, porphyritic, and other unstratified rocks. The commonest forms of the crystals are six-sided pyramids, and six-sided prisms terminated by six-sided pyramids. Quartz crystals may be cleaved, though with great difficulty, parallel to all the faces of the common crystal, producing a rhomboid, which is the primitive form.

The following are the external characters. *Fracture*, commonly conchoidal. *Lustre*, vitreous, inclining in some varieties to resinous. *Transparency*, of various degrees, from quite transparent to translucent or opaque. *Hardness:* scratches glass, does not yield to the knife; when compact enough, gives sparks with steel. *Powder*, white. *Phosphorescence:* some varieties yield a phosphorescent light, and an empyreumatic odour when rubbed. *Specific gravity*, 2·6 to 2·7. *Before the blowpipe*, infusible alone.

Crystals of quartz often enclose foreign bodies, such as water, air, chloride, bitumen, crystals titanite, &c. They also acquire various shades of colour from minutely-divided foreign matter, intimately blended in their composition. The following are the names by which some of the varieties of coloured quartz are known.

Rock Crystal. This name is given to the most perfectly transparent crystallized specimens, and to some transparent or semitransparent massive varieties. The finest specimens are from the Alps of Salzburg, the Tyrol, Switzerland, Dauphiny, Piedmont, Madagascar, Ceylon, and Brazil.

Milk Quartz. Opaque quartz, both massive and crystallized, nearly of the colour of milk. The crystals of this, and of all coloured varieties of quartz, are more regular in their forms than those of transparent quartz.

Rose Quartz. A variety of milk quartz, both crystallized and massive, translucent, and of a rose-red, supposed to derive its colour from manganese. The finest and most transparent varieties, which are cut and polished, and are known among jewellers as *Bohemian rubies*, are from Bohemia, Bavaria, and Siberia. The varieties approaching milk quartz are from Norway, France, and Spain.

Amethyst. Colour, various shades of violet and purple, the colouring matter being, in all probability, manganese and iron. The finest specimens are from Brazil, Ceylon, India, Siberia, Persia, and Spain. It is found also less transparent and well coloured in almost every country of Europe. *British Localities:* Several of the mines of Cornwall; the traps of Fifeshire, and of Kinnoul Hill, in Scotland; the neighbourhood of Cork, and Achil Island, county of Mayo, Ireland.

Yellow Quartz. *The Bohemian Topaz*, of various shades of yellow, and nearly transparent, is found chiefly in Bohemia; also in some of the mines in Cornwall; and with brown quartz at Cairngorm, in Aberdeenshire.

Brown or Smoke Quartz, or Cairngorm, is found in several parts of Europe; some fine crystals, of various shades, are from alluvial soil near Cairngorm, whence one of its names.

Prase. Quartz coloured leek-green, by an admixture of chlorite, from Breitenbrun, in Saxony; also from Iona, one of the Hebrides.

Avanturine. Quartz enclosing mica. The finest varieties are from Spain, and are of a reddish colour, enclosing spangles of mica of a golden hue. It is found in Glen Ferrat, in Scotland, of a fine bluish-gray colour.

Ferruginous Quartz, or Eisenkrest. Colour, different shades of red and yellow, derived from a small portion of oxide of iron. It occurs, both crystallized and massive, in Bohemia, Franconia, the Hartz mountains, and Altenberg, in Saxony. *British Localities:* Bristol; trap rocks near Dunbar; and Rathlin Island, on the coast of Antrim. A fine crystallized variety called the *Hyacinth of Compostella,* occurs near Compostella, in Spain, and in Washington County, North America.

Irisated Quartz. Shows a prismatic play of colours, either superficial or internal. The former is occasioned by the deposit of some metallic oxide, the latter by the refraction of light in consequence of fissures in the crystal.

Fibrous Quartz. Common quartz sometimes shows a columnar composition. If these columns be thin, parallel, strongly coherent, and more or less bent, the variety is called *fibrous* quartz. If they are nearly impalpable, and scarcely to be observed, except in the opalescent light exhibited when cut with a convex surface, the specimen is called *cat's-eye.*

Chert, or Hornstone, Fint, Flinty Slate, Lydian Stone, Calcedony, Cornelian, Agate, Chrysoprase, Plasma, Heliotrope, and Jasper, are massive varieties of quartz, occasioned by differences in the size and mode of aggregation of the component parts, or by the admixture of other earths. Jasper consists of quartz, alumina, and oxide of iron, and sometimes constitutes beds of considerable extent.

Felspar.

Next to quartz and oxide of iron this is the most generally diffused of any mineral. It occurs in rhomboidal crystals, in granite, porphyry, trachyte, and basalt; in composite crystals in cavities in granite; in rolled crystals in conglomerates; decomposed in porcelain clay; and in some granites and sandstones. It admits of cleavage, with greater or less facility, into an acute-angled parallelopipedon, which is considered the primary form.

Fracture, in one direction lamellar; cross fracture uneven. *Lustre,* vitreous, inclining to pearly on the lamellar fracture—that of the cross fracture glimmering. *Hardness:* scratches glass;

yields with some difficulty to the knife. *Colour:* the prevailing colour is white; sometimes flash-red, and green. *Streak,* white or grayish. *Specific gravity,* 2·54. *Composition,* according to an analysis by Klaproth, of common felspar from Carlsbad,—silica 64·50, alumina 19·75, potassa 11·50, lime a trace, oxide of iron 1·75, water ·75. *Chemical characters:* gives out no water when heated; fuses before the blow-pipe into a white enamel; is insoluble in acids. The solution of it when treated with nitrate of baryta, nitric acid, and carbonate of ammonia, leaves on evaporation an alkaline residue, which yields a precipitate with chloride of platinum, and gives few or no efflorescent crystals with sulphuric acid.

Labradorite, or Opalescent Felspar, is of a smoke-gray colour, and affords beautiful and varied tints of blue, green, red, and yellow, when viewed in particular directions. *Structure,* lamellar. *Transparency,* translucent at the edges. *Lustre,* glimmering. *Composition:* it differs from common felspar in containing soda instead of potassa.

Albite: Soda Felspar. *Before the blowpipe* and with *acids,* has the same characters as the last. Its solution after fusion with nitrate of baryta, when treated with carbonate of ammonia, gives an alkaline residue, which forms efflorescing crystals of sulphate of soda with sulphuric acid.

Compact Felspar.

The substance called compact felspar appears to require some other name. It approaches in composition nearer to Labradorite than to the common felspar, and contains soda as well as potassa. It occurs in large masses, both as a simple rock, and entering as an ingredient into a number of compound rocks. As a simple rock it is thus described by Dr. M'Culloch:—"Colour, various shades of green, brown red, pale gray, white, dark gray, purple, and black. The fracture is compact, uniting the small splintering with the flat or imperfectly conchoidal. It is less hard than quartz, but resists ordinary steel. It generally possesses a peculiar aspect on the surface, resembling that of wax, which is highly characteristic; and it may assist beginners to say that, except in hardness and refusing to effervesce with acids, it very strongly resembles in external characters, many of the compact and smooth varieties of limestone."* It occurs in gneiss in large flattened masses or beds like the beds of limestone in the same situation, and in smaller lumps, or contemporaneous veins, as they are sometimes called, originating and terminating in the mass in which they lie; also as single laminæ in gneiss possessing the granitic or schistose character. It constitutes likewise the basis of many of the trap family of rocks. Rocks consisting principally of compact felspar, may be known by the white appearance they assume on a weathered surface.

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* McCulloch's Classification of Rocks.

Dr. M'Culloch has remaked that, in the trap family, the predominant substance is a simple rock, at one extreme of which may be placed wacke, or indurated clay, and at the other compact felspar, the intermediate members being claystone and clinkstone.

CLINKSTONE—PHONOLITE.

This mineral constitutes, as we have before observed, simple rocks, which are massive, columnar, or with a thick slaty structure. *Fracture*, even or imperfectly conchoidal, sometimes splintery. It assumes a granular appearance by weathering, and is destitute of the waxy appearance of compact felspar, which it much resembles. It yields with greater or less facility to the knife, as it passes, on the one hand, into compact felspar, and on the other into claystone. It is of various colours. It emits a ringing metallic sound when struck by a hammer, whence its name. This, however, is by no means a distinctive character, as it is possessed by many other rocks, and by some in a much higher degree. Clinkstone is composed principally of compact felspar.

CLAYSTONE.

This substance forms the whole of some, and the greater portion of many other rocks. It occurs in various degrees of induration, from wacke, the softest of the trap family, to jasper and siliceous schist, the hardest of rocks.

MICA.

This mineral occurs confusedly crystallized as one of the constituents of granite, gneiss, and mica slate, and as nodules and concretions in those rocks; crystallized in hexagonal plates in granite, porphyry, lava, and primary limestone; as abraded scales in sands, sandstones, shales and clays. Its primary *form* is considered to be a right rhomboidal prism, the angles of which are 60° and 120°. *Colour*, various shades of white, yellow, green, brown, and occasionally black. *Cleavage:* mica is easily divided parallel to the terminal planes of its crystals. *Fracture*, scarcely observable, uneven. *Lustre*, vitreous, pseudo-metallic. *Transparency:* sufficiently transparent in thin plates to be used as a substitute for glass. *Touch*, smooth, but not unctuous. *Hardness:* yields readily to the knife, but the edges of the crystals will scratch glass. *Powder*, grayish-white. *Elasticity:* this quality distinguishes it from talc, which is flexible, but not elastic. *Specific gravity* about 2·0 to 2·5. *Before the blowpipe,* mica from different localities varies considerably in its pyrognostic characters, but is in general fusible with difficulty into a gray or black enamel. *Composition:* the analyses of several varieties of mica from different localities, by Klaproth, Rose, and Peschier, give very different results, as will be seen from the following table :*

INGREDIENTS.	Mica from Zinnwald.	From Siberia.		From St. Gothard.	From Kimito.
Alumina	20·00	34·25	22·00	0·00	36·80
Silica	47·00	48·00	40·25	19·50	46·36
Oxide of iron	15·50	4·50	8·75	26·50	4·53
Oxide of titanium	0·00	0·00	13·00	25·40	0·00
Oxide of manganese . .	1·75	a trace.	2·00	25·25	0·00
Magnesia	0·00	0·50	0·00	0·00	a trace.
Lime	0·00	0·00	1·75	0·00	0·00
Potassa	14·50	8·75	7·25	0·00	9·22
Fluoric acid and water	0·00	0·00	3·24	0·00	1·81
	Klaproth.	Klaproth.	Peschier.	Peschier.	Rose.

TALC.

TALC is very closely allied to mica; it occurs crystallized in some granites, massive and earthy in veins in talcose schists and primary limestones.

CRYSTALLIZED TALC. *Form of crystals,* hexagonal tables. The primary is a right rhomboidal prism of 120° and 60°, according to Haüy. *Structure,* lamellar, the laminæ easily separated. *Colour,* silver white, yellowish, and of various shades of green. *Lustre,* splendent, pearly. *Transparency,* translucent. *Hardness,* yields to the nail, soft, sectile. *Flexibility,* flexible, but not elastic. *Streak,* leaves a pearly white streak when drawn over paper. *Touch,* unctuous. *Specific gravity,* 2·8. *Before the blowpipe* specimens from different localities vary much in their habitudes. In the matrass, talc gives off water, whitens and exfoliates, but does not fuse; but some varieties yield, with difficulty, a white enamel, attackable by nitric acid. *Composition.* This likewise varies with the locality of the specimen. According to Klaproth, it consists of silica 61·00, magnesia 30·55, potassa 2·75, oxide of iron 2·50. The analysis of Vauquelin, afforded no potassa.

MASSIVE TALC is less flexible and translucent than common talc. *Colour,* apple-green. *Structure,* sometimes radiated. It constitutes extensive beds in mica, schist, gneiss, and serpentine. *British Localities:* Banffshire and Aberdeenshire; also Glen Tilt, in Perthshire: Lizard Head, Kyans Cove, and Porthallo, in Cornwall.

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* From Mohs's Treatise on Mineralogy.

INDURATED TALC, massive. *Colour*, greenish gray. *Structure*, schistose and curved, shining. *Lustre*, pearly, somewhat translucent. *Touch*, soft and unctuous. *Specific gravity*, 2·9. *British Localities:* Perthshire, Banffshire, the Shetland Isles, and the Lizard in Cornwall.

CHLORITE.

CHLORITE occurs crystallized in veins and in cavities in granite, &c., enclosed in crystals of quartz, felspar, and other minerals, in such quantities as to impart a green colour to them, sometimes coating the surface; massive in chlorite schists and clay-slates.

CRYSTALLIZED CHLORITE. *Form*, flat six-sided prisms, divisible into thin laminæ parallel with their terminating planes. *Colour*, dark green, yellowish green, and grayish. *Lustre*, shining, between pearly and vitreous. *Transparency*, opaque. *Fracture*, uneven. *Hardness*, yields to the nail. *Powder*, greenish-gray. *Touch*, unctuous. *Odour*, yields an earthy smell when breathed upon. *Before the blowpipe*, in the matrass alone, gives off water, and afterwards fluoric acid, known by its turning Brazil-wood paper yellow, and by depositing silica on the glass. On charcoal *alone* it melts into a black globule with a dull surface. With *borax*, gives a green glass; with *microcosmic* salt, decomposes, forming a glass coloured by iron, and leaving a skeleton of silica. With *soda*, neither fuses nor intumesces, but the assay is rounded on the edges.

EARTHY CHLORITE occurs in friable or loosely aggregated grains, adhering or incrusting.

COMMON, or MASSIVE CHLORITE, is the same as the last, but the grains are more closely united, of a weakly glimmering lustre and earthy texture.

WHITE SILVERY CHLORITE. Pearly, greenish-white scales, occurring in masses, but adhering so slightly as to be separated by the finger.

CHLORITE SLATE. *Structure*, slaty, of a glistening resinous lustre. It occurs in beds in St. Gothard, Saltzburg, Sweden, Corsica, Jura, Anglesey, and part of Caernarvonshire.

GREEN EARTH, a variety of chlorite, found in small globular masses, lining cavities in amygdaloidal trap. *Colour*, grayish or bluish green, passing into blackish green. *Lustre*, dull. *Fracture*, generally earthy. *Hardness*, yields to the nail. It is found in Saxony, Bohemia, near Verona, Kinnoul Hill, near Perth, and in the amygdaloidal traps of the county of Antrim.

The greenish masses in the sand beneath the chalk of England, known by the name of the *Green Sand*, are considered to belong to a variety of this mineral. The following table shows the difference in composition of some of these chloritic minerals, according to the analysis of Vauquelin.

	Earthy Chlorite.	Slaty Chlorite.	Green Earth.
Silica	26·00	29·50	52·00
Magnesia	8·00	21·39	6·00
Oxide of iron	43·00	23·39	23·00
Alumina	18·05	15·62	7·00
Water	——	7·38	4·00
Potassa	2·00	0·00	7·50
Lime	0·00	1·50	0·00

Hornblende, or Amphibole.

This mineral occurs crystallized with felspar and quartz, in some granites, in syenite, greenstone, basalt, and lava; also in hornblende rock, and hornblende slate. *Form of the crystal:* the primitive form, ascertained by Haüy, by reflection on fragments, is an oblique rhomboidal prism of 124° 36′ and 55° 24′. It occurs occasionally in rhomboidal crystals, but more frequently confusedly aggregated; sometimes the crystals are long, flat, six-sided, and prismatic, and are often striated longitudinally. *Colour*, dark bottle-green, brownish-green, or brown, approaching to black. *Lustre*, shining. *Transparency*, the dark varieties opaque, the green varieties translucent at the edges. *Fracture*, crystalline, exhibiting fibres confusedly aggregated. *Hardness*, yields easily to the knife; scratches felspar, is scratched by quartz. *Frangibility* tough, and difficult to break;—indented by the hammer. *Powder*, greenish gray. *Specific gravity*, 3·6. *Before the blowpipe*, gives out no water, fuses easily into a black glass, scarcely soluble in acids, its solution yields a precipitate with oxalate of ammonia, and a copious precipitate with ferroprussiate of potassa.

Massive Hornblende is of a crystalline structure composed of long crystals, intersecting each other, sometimes confusedly radiated. It frequently has a ferruginous appearance on the surface from decomposition.

Hornblende Slate differs only from the massive, in having a schistose structure.

Basaltic Hornblende generally occurs in single crystals, and is sometimes magnetic. The primitive form of the crystal is the same as that of common hornblende. It is of a black colour, vitreous lustre, and hard enough to scratch glass. Its specific gravity is 3·25.

The composition of common and basaltic hornblende, according to Klaproth, is given below:—

	Common Hornblende.	Basaltic Hornblende.
Silica	42·00	47·00
Alumina	12·00	26·00
Lime	11·00	8·00
Magnesia	2·25	2·00
Oxide of iron	30·00	0·00
Iron	——	15·00
Ferruginous manganese	0·25	
	0·25	

Common hornblende is found in a great variety of rocks, and often enters largely into their composition. Its British localities are Mullyan Cove, Cornwall, in greenstone; abundantly in the traps, greenstones, and basalt of the coal-measures, and of the slate-mountains of the Cambrian and Cumbrian chains; in the syenites, mica slate, and gneiss of Scotland and Ireland, and in the trap rocks of those two countries. Basaltic hornblende, occurs in the basaltic rocks of most parts of Europe.

AUGITE, OR PYROXENE.

AUGITE occurs crystallized with felspar in augitic greenstone, augitic basalt, and lava, and in primary limestone. *Form of the Crystal:* the primary form, according to Haüy, is an oblique rhomboidal prism, of 87° 5′ and 92° 55′. It is generally found in small crystals, of six and eight sides, terminated by diedral summits. It also occurs in grains and amorphous. *Colour*, usually dark green, brown, and sometimes black. *Lustre*, vitreous. *Fracture*, conchoidal. *Hardness*, scratches glass, and sometimes gives sparks with steel. *Specific gravity*, 3·3. *Before the blowpipe* gives off no water, melts with difficulty, and only in small portions, into a black enamel. Its solution indicates with reagents the presence of lime and oxide of iron, and gives trifling or no indications of magnesia. Its difficulty of fusion is one character by which it is distinguished from hornblende, which it much resembles; the difference in the angles of the primitive forms of the two minerals is another.

Hornblende and augite are very closely allied. Crystals possessing the form and structure of augite, were observed by Mitscherlich, in the slags of many foundries in Sweden and Germany; and on fusing in a porcelain furnace a mixture of silica, lime, and magnesia, in the proportions in which they are found in augite, crystals were produced, having the form and structure of augite; but crystals of hornblende could not be obtained by a similar process. Professor Rose accounted for the production of augite, and non-production of hornblende, by attributing it to the effect of rapid cooling; and this conjecture he confirmed, by fusing, in a platinum crucible, a light green variety of hornblende, which, on cooling, formed fibrous tufts of dark crystals, which were found, on measurement by Wollaston's reflecting goniometer, to have the angles of augite. A specimen of diopside, a green translucent variety of augite, being submitted to the same process, cooled into a dark mass, but regained its former structure. Augite, therefore, is formed when the process of cooling is rapid, and hornblende when it is slow. The rocks in which these two minerals are found, are another proof of this. Hornblende is usually found in syenite, trachyte, and lava, accompanied by quartz, felspar, and albite, minerals which require for their formation a slow process of cooling: while augite occurs in basalt and lava, in company with olivine, which has also been recognised in the scoriæ of several foundries.

Actinolite.

This mineral occurs in veins in hornblende slate, gneiss, mica slate, and limestone. It is of a pale green colour, and may be divided in three varieties,—Crystallized, Asbestiform, and Glassy Actinolite.

Crystallized Actinolite. *Form*, single prisms, or columnar masses, consisting of hexaedral prisms. *Colour*, leek-green. *Fracture*, fibrous and scopiform. *Lustre*, shining, sometimes silky. *Transparency*, varies from translucent to transparent. *Hardness*, scratches glass. *Specific gravity*, 3·3. *Composition*, according to Bergman, silica 64·00, alumina 2·70, lime 9·30, magnesia 20·00, oxide of iron 4·00. *Before the blowpipe*, it melts into a greenish-gray glass.

Asbestiform Actinolite. *Form*, massive, and in capillary crystals, disposed in wedge-shaped masses, or in radii, which are green, greenish-gray, and brownish-green, opaque, or slightly translucent at the edges. *Composition*, nearly the same as the preceding.

Glassy Actinolite differs from the asbestiform in having an external lustre, vitreous, inclining to pearly, and in being translucent and brittle. Actinolite is found in the Tyrol, in St. Gothard, near Salzburg, in Norway, and in Piedmont. *British Localities:* near Lostwithiel, and St. Die, in Cornwall, in copper and tin veins, and at St. Michael's Mount, in asbestiform rocks: at Llanberris, Caernarvonshire, in greenstone; in globular concretions in the amygdaloid of Caer Caradoc, in Wales, and in the Isle of Lewis.

Hypersthene.

Hypersthene occurs crystallized with felspar in hypersthene rock, hypersthenic syenite, hypersthenic greenstone, and hypersthenic granite. *Structure*, lamellar. *Cleavage*, parallel to the sides of a quadrangular prism of about 93°, more perfect parallel to the short diagonal of that prism; indications of cleavage parallel to the long diagonal. *Colour*, dark brown, or greenish black. *Lustre*, on the fractured surface, pseudo-metallic, of a copper red, or a greenish colour, observable in one direction, but not in the other. *Transparency*, opaque. *Hardness*, yields to the knife. *Powder*, dark gray. *Specific gravity*, 3·38. *Fracture*, uneven. *Composition*, by Klaproth's analysis, silica 54·25, alumina 2·25, lime 1·25, magnesia 14·00, oxide of iron 34·50, water 1·00, with a trace of oxide of manganese. *Before the blowpipe*, gives off no water; heated *alone*, it is but little altered, but upon charcoal melts into a greenish-gray opaque globule, easily soluble in borax, insoluble in acids. This mineral was first discovered in rolled masses on the coast of Labrador, and thence called Labrador hornblende. It also occurs in a rock analogous to syenite, or greenstone, consisting chiefly of Labrador felspar. It has been observed in serpentine, in Coverack Cove, in Cornwall.

DIALLAGE.

This mineral occurs crystallized with felspar in diallage rock; obscurely crystallized, and fine grained in serpentine. *Cleavage*, in two directions; in one the cleavage is highly perfect, and easily obtained; the other appearing only in slight traces. *Colour*, olive green, inclining to blackish green. *Lustre*, inclining to metallic on the perfect faces of cleavage, vitreous on the other faces. *Transparency*, opaque, translucent on the edges. *Hardness*, yields to the knife. *Powder*, grayish white. *Specific gravity*, 3·1. *Composition:* its constituents, according to the analysis by Bonsdorf, are

	A Green Variety.	A Black Variety.
Silica	46·26	45·69
Magnesia	19·03	18·79
Lime	13·96	13·85
Alumina	11·48	12·18
Protoxide of Iron	3·43	7·32
Protoxide of Manganese	9·36	0·22
Fluoric Acid	1·60	1·50
Water and foreign substances	1·04	0·00

Before the blowpipe, it gives off water, and fuses into a blackish enamel, sparingly soluble in acids. *Foreign Localities:* Basta in the Hartz, in greenstone; Zöoblitz in Saxony, Salzburg, and the Tyrol, in serpentine. *British Localities:* the Isle of Anglesey, Coverack Cove, and near St. Keverne, in Cornwall; between Ballantrae and Girvan, in Ayrshire; and at Portsoy, in Banffshire, in serpentine; in Fifeshire, in greenstone rocks; and in porphyritic rocks in Calton Hill, and Dunbarton.

Steatite, or Soapstone.

Steatite is found in considerable masses and beds in serpentine granite, clay slate, and also in veins. Serpentine is the rock in which it usually occurs. *Form*, massive. In Franconia it occurs with occasional appearances of crystallization, which are generally considered pseudo-morphous, resembling the forms of the quartz or carbonate of lime with which it is associated. *Colour*, white, passing into gray, green, yellow, and red. *Lustre*, dull—lustre of the streak faintly resinous. *Fracture*, uneven, splintery. *Hardness*, yields to the nail, sectile. *Touch*, unctuous, does not adhere to the tongue. *Transparency*, somewhat translucent at the edges. *Specific gravity*, 2·67. *Composition:* we give the results of an analysis by Vauquelin, and of two others by Klaproth, of steatite from different localities :—

		From Baireuth.	From Cornwall.
Silica	64·00	59·50	45·00
Magnesia	22·00	30·50	24·75
Alumina	0·00	0·00	9·25
Oxide of Iron	3·00	2·50	1·00
Water	5·00	5·50	18·00
	Vauquelin.	Klaproth.	Klaproth.

Before the blowpipe, gives off water, whitens and hardens, is fusible with difficulty, at the edges of the assay. *Foreign Localities:* Freyberg, and in the principality of Baireuth, in Saxony; in Bohemia, Norway, Sweden, and France ; also in Maryland, Pennsylvania, and Connecticut, in North America. *British Localities ;* in serpentine, the serpentine districts of Cornwall and Anglesey, and at Portsoy, in Scotland ; in wacke, in the Isle of Skye, and others of the Hebrides.

Serpentine.

Serpentine often constitutes masses of simple rock, and is found sometimes intermixed with crystalline limestone, constituting the marble known by the name of Verde Antique; but it enters into the composition of no other mixed rocks, except as rolled masses in conglomerates. From the great variations in its composition, it ought to be regarded rather as an indefinite earthly compound, than a simple mineral. Mineralogists divide serpentine into two kinds, Noble and Common. Noble Serpentine occurs massive. *Fracture*, splintery, passing into conchoidal. *Colour*, various shades of green, and yellowish green. *Lustre*, translucent, glimmering or glistening, resinous. *Touch*, somewhat unctuous. *Hardness*, yields to the knife, sectile. *Powder*, white. *Specific gravity*, 2·5. *Composition:* the first analysis is by Hisenger, the second by John :—

Silica	32·00	42·50
Magnesia	37·24	38·63
Alumina	0.50	1·00
Lime	10·20	0·25
Oxide of Iron	6·00	1·50
Oxide of Manganese	0·00	0·62
Oxide of Chrome	0·00	0·25
Water	14·00	15·20

NOBLE SERPENTINE is found in beds and masses in primary limestone, gneiss, and mica slate. *Foreign Localities:* in Italy, Silesia, Sweden, Bohemia, and the Tyrol; at Connecticut and Newbury Point, Massachusetts, in crystalline limestone. *British Localities:* in the marble of Glen Tilt in Scotland; in veins, in common serpentine, in the Isle of Anglesey, and Cornwall, and in the county of Galway, Ireland.

COMMON SERPENTINE is of various shades of green, brown, and red, the brown most prevalent,—the colours variously intermixed and blended in stripes and blotches. *Fracture*, uneven, occasionally approaching the flat conchoidal. *Lustre*, generally dull and opaque, sometimes translucent at the edges. *Hardness*, variable, sometimes scarcely yielding to the knife. *Before the blowpipe*, noble and common serpentine in the *matrass* give off water and blacken; on *charcoal*, turn white, and, in a good heat, melt on the thin edges into an enamel; with *borax*, melt slowly into a clear green glass. *Localities* for common serpentine are the same as for the preceding variety, and also the following: Portsoy, Banffshire; and at the Bridge of Corlachie, Forfarshire; in Ayrshire; near Burnt Island, Fifeshire; in the Shetland Isles, Unst and Fetlar; and in Glass, one of the Hebrides.

CARBONATE OF LIME.

This mineral, which is so generally diffused, enters but sparingly into compound rocks, as one of their ingredients. In them it occurs chiefly as veins, but considerable masses of it form particular beds in other rocks, or constitute rocks themselves. It is more abundant in the more recent than in the older strata. It is found crystallized in veins, cavities of rocks, fossil remains, and stalactites, and in beds of primary limestone; it occurs also massive and amorphous (its most common form,) as limestone strata. The crystalline varieties of limestone generally occur in the older rocks, the compact and earthy varieties in the more modern; it occurs also concretionary in oolites; fibrous in some limestones and organic remains; as nodules in amygdaloidal traps; lamellar in organic remains; earthy and pulverulent in chalk, marl, and some kind of limestone.

Form: crystals of calcareous spar, or pure carbonate of lime, are found under a great variety of forms, all resolvable, by cleavage, into an obtuse rhomboid of 105° 5′ and 74° 55′. *Fracture:* the cross fracture is conchoidal, but not easily obtained.

Colour, various. *Lustre*, between pearly and vitreous. *Transparency*, more or less transparent; the purer varieties refract doubly. *Hardness*, yields easily to the knife. *Powder*, grayish-white. *Specific gravity*, 2·7. *Composition :* lime 57, carbonic acid 43. It effervesces in acids from the disengagement of carbonic acid gas; its solutions yield an abundant white precipitate with oxalate of ammonia. *Before the blow-pipe*, all varieties of carbonate of lime exhibit the following characters: are infusible alone on charcoal, do not colour the flame of the blowpipe, but shine with great brightness when the carbonic acid is driven off. By calcination they lose about 43 per cent. of this acid; the calcined mass becomes caustic, disengages heat when moistened with water, and has an alkaline reaction on test papers. With the *fluxes*, carbonate of lime dissolves with effervescence and fuses into a glass, transparent while hot, milky when cold. Carbonate of lime is so generally diffused that no list of localities can be given. The most rare and beautiful varieties of calcareous spar are derived from Derbyshire and the North of England; while in Cornwall it is extremely rare.

Carbonate of Magnesia.

Magnesite, or carbonate of magnesia, occurs amorphous, fibrous, and spongiform, also pulverulent. *Colour*, gray or yellowish, with dendritic delineations. *Fracture*, splintery or flat conchoidal. *Lustre* and *Transparency*, dull and opaque. *Hardness*, yields to the nail externally, internally is harder than calcareous spar. *Touch*, meagre; adheres to the tongue. *Specific gravity*, 2·8. *Composition :* according to an analysis of a specimen from Styria, by Klaproth, its constituents are, magnesia 48, carbonic acid 49, water 3. It dissolves with slow effervescence in acids, yielding, with sulpuhric acid, crystals of sulphate of magnesia. *Before the blowpipe*, it crackles, shrinks, and hardens on charcoal, and then has an alkaline reaction on test papers. *Localities :* in Moravia and Styria, and at Baudissero and Castellamonte, in Italy; at Vallecas, in Spain; Baumgarten, in Silesia; and near Baltimore, North America,—all in serpentine.

Carbonate of magnesia, combined with carbonate of lime, occurs crystallized, under the name of bitterspar, in veins, in chloritic rocks, serpentine, dolomite and magnesian limestone.

Bitterspar.

Form, a rhomboid, differing from that of carbonate of lime in the value of its angles, which are 106° 15′, and 73° 45′, by the reflecting goniometer. This is the primary form, to which other varieties of its crystals may be reduced by cleavage. *Colour*, grayish, or yellow, sometimes inclining to green or red. *Lustre* and *Transparency,* pearly, semi-transparent. *Fracture,* foliated. *Hardness* and *Frangibility,* scratches calcareous spar, brittle. *Powder,* grayish-white. *Specific gravity,* 3·0. *Composition,* 52·0 carbonate of lime, 45·0 carbonate of magnesia, 3·0 oxide of iron and manganese. It dissolves slowly and with but slight effervescence in cold nitric acid. The solution yields little or no precipitate with oxalate of ammonia, but gives a considerable precipitate with potassa after having been treated with a hydrosulphuret. *Before the blowpipe,* it is not to be distinguished from calcareous spar.

Localities: in the mountains of the Tyrol and Salzburg, in the mountains of Talberg, in Sweden, and of Chalance, in Dauphiny; in Scotland, on the borders of Loch Lomond, in chlorite schist, and near Newtown Stewart, in Galloway; also in the Isle of Man, in compact dolomite, and in the magnesian limestone of the north of England.

Dolomite.

A massive variety of the carbonate of lime and magnesia, resembling granular limestone, but much softer.

Structure, consisting of fine grains, which are lamellar. *Colour,* white, sometimes with a tinge of green or gray. *Lustre* and *Transparency:* internal lustre glistening, translucent at the edges. *Hardness,* yields to the nail. *Phosphorescence,* frequently emits a phosphorescent light when struck in the dark. *Specific gravity,* 2·8. *Composition,* 59 carbonate of lime, 40 carbonate of magnesia. Its action with acids and before the blowpipe has been described under bitterspar. *Localities:* in Sweden, France, Saxony, the Pyrenees, Apennines, &c. It is also found in the island of Iona, in a bed about forty feet wide, in hornblende rock.

Magnesian Limestone occurs abundantly as a rock formation in England, ranging from Nottingham to Sunderland. It is likewise found in beds in the Mendip Hills, and in the carboniferous limestone series near Bristol, and Ballyshannon and Howth in Ireland. It differs from common limestone in having a granular sandy structure, a glimmering or glistening lustre, and a yellowish colour. Its characters with acids and before the blowpipe are the same as those of dolomite. It consists, of lime about 30, magnesia 21, carbonic acid 47, clay and oxide of iron 1.

Sulphate of Lime.

Sulphate of Lime occurs crystallized in beds of clay, under the name of selenite; fibrous, compact, and pulverulent, under the name of *Gypsum.*

Crystallized Gypsum, or Selenite. *Form:* it occurs generally in flat crystals, which are oblique parallelopipedons. The primary form is considered by Haüy to be a right rhomboidal prism, the bases of which are oblique-angled parallelograms of 113° 8′ and 66° 52′. *Structure*, lamellar, the cleavage in one direction perfect and easily obtained; but imperfect and obtained with difficulty in the others. *Colour*, various shades of white, gray, and brown; sometimes colourless and highly transparent. *Lustre*, shining, pearly. *Transparency*, more or less transparent. *Hardness*, yields to the nail, sectile. *Flexibility:* divided into thin laminæ it is flexible, but not elastic. *Specific gravity*, about 3·0. *Composition*, lime 32·7, sulphuric acid 46·3, water 21. *Before the blowpipe*, it gives off water in the matrass, and becomes friable. If reduced in this state to an impalpable powder, and mixed with water, it evolves heat, and soon hardens into a solid mass. Held in the forceps, and urged with a stronger flame, it exfoliates and melts, though with some difficulty, into a white enamel. Fused with an alkali it forms a mass which exhales sulphuretted hydrogen, when moistened with acidulated water. The solution yields a precipitate with an oxalate, none with a sulphate, and forms by evaporation deliquescent acicular crystals. *Localities:* selenite is found in almost every country in Europe. In England it occurs in the London clay, and in another clay, lower in the series of rocks, called the Oxford clay. From the pits at Shotover Hill, near Oxford, very beautiful crystals are obtained.

Fibrous Gypsum, a very beautiful mineral, occurs massive, composed of delicate and nearly separate fibres, either straight or curved. *Colour*, generally white, but various, like that of selenite. *Lustre*, glistening, pearly; translucent. *Fracture*, cross, lamellar, and very brilliant. *Hardness*, yields to the nail. *Localities:* occurs at St. Gothard, in beds, in gneiss; in the Valais in hornblende slate: in several countries of Europe and America in the fossiliferous series.

Compact Gypsum, or Alabaster. Massive. *Fracture*, compact or slightly splintery. *Lustre*, dull, or glimmering, translucent at the edges. *Hardness*, yields to the nail. *Colours*, are nearly the same as those of selenite, but it sometimes occurs mottled. *Localities:* met with in several countries of Europe and North America. It occurs in Derbyshire and in other parts of the new red sandstone districts of England.

Bitumen.

There are three varieties of bitumen: earthy bitumen, or mineral tar; elastic bitumen, or mineral caoutchouc; compact bitumen, mineral pitch, or asphaltum. Bitumen occurs solid or liquid in some limestones, and in organic remains and veins; also disseminated invisibly through the substance of beds of coal, and of certain shales and limestones.

Earthy Bitumen. Amorphous, earthy, blackish brown, dull, sectile, very soft, taking an impression from the nail, possesses the peculiar odour known as the bituminous; burns with a brisk clear flame, and an agreeable smell, with the deposit of much soot; soluble in alcohol. It is found in France, Persia, the Hartz.

Elastic Bitumen occurs in nodular masses of various shades of brown; soft, yielding easily to pressure; flexible, elastic, sectile, of a strong bituminous odour, burns with a strong flame and much smoke, melts at a gentle heat. *Specific gravity*, about 1·0. It removes the traces of a pencil on paper like caoutchouc or Indian rubber, whence its name. Elastic bitumen consists chiefly of bituminous oil, hydrogen, and charcoal. It has hitherto been found only at Castleton, in Derbyshire.

Compact Bitumen; Asphaltum. Massive. *Colour*, brownish-black to black. *Fracture*, conchoidal, brittle. *Lustre*, shining; resinous; opaque; gives out the bituminous odour when rubbed. *Specific gravity*, 1·0 to 1·6. It burns freely, leaving a small quantity of ashes, insoluble in alcohol. It consists chiefly of bituminous oil, hydrogen, and charcoal, the latter being in much greater proportion than in the preceding variety. Oxide of iron, and two or three of the earths, are sometimes present in small quantities. *Localities:* found in France; at Neufchatel, in Switzerland; in large strata at Aolona, in Albania; in lumps on the shores, or floating on the lake in Palestine, called the Dead Sea. It is obtained in large quantities from the islands of Barbadoes and Trinidad; in the latter in such profusion as to be used mixed with grease for dressing the bottoms of ships.

Oxide of Iron.

Oxide of Iron occurs crystallized in lava, syenite and hypersthene rock, and minutely disseminated through sandstones, clays, ironstones, ochres, and almost every rock.

Crystallized Oxide of Iron; Iron Glance; Specular Iron. *Form*, lamellar, and crystallized in various shapes, the primitive being a slightly acute rhomboid of 87° 9′, and 92° 51′. *Structure*, lamellar. *Fracture*, cross fracture uneven, passing into conchoidal. *Colour*, deep steel gray. *Lustre*, splendent, metallic, frequently tarnished, and beautifully iridescent. *Transparency*, opaque in large fragments, but the edges of thin small ones are blood-red by transmitted light. *Hardness*, scratched by the knife. *Powder*, cherry red, slightly *magnetic* when pulverized. *Specific gravity*, 5·0. *Composition:* it consists entirely of peroxide of iron. *Before the blowpipe*, it is infusible without the addition of fluxes, but becomes magnetic:—colours glass of borax a dirty yellowish green. It occurs in veins and beds in the older rocks. *Foreign Localities:* found in great abundance, and in crystals of great beauty, in the isle of Elba, the iron mines of which have been worked from a very remote antiquity. In Saxony and Bohemia in mica schist; at the foot of the great St. Bernard; at Maryland in gneiss; and in South America and Siberia. *British Localities:* in Britain it occurs finely crystallized in St. Just, and Tin Croft mine, in Cornwall, in clay slate; at Cumberland, in Lanarkshire; at Eskdale, in Cumberland, and various other localities.

VOLCANIC IRON GLANCE occurs in very flat crystals, often with curvilinear faces intersecting each other. It is less splendent than the last

MICACEOUS IRON GLANCE. Minute shining scales, either loose or slightly cohering. *Colour,* by reflected light, iron black, with occasionally a tinge of red; by transmitted light, of blood-red colour.

SULPHURET OF IRON, OR IRON PYRITES.

SULPHURET OF IRON occurs in veins and beds, also disseminated through clay slates and primary limestones and shales. It is found amorphous, mammillated, globular, cellular, stalactical, pseudo-morphous, capillary, and crystallized in the cube and octoedron. It is found also enclosed in other minerals, and investing them. The organic remains of some shales and clays are mineralized by it.

Form: the octoedron may be considered the primary form, but common pyrites have no regular cleavage. *Fracture,* granular or uneven, sometimes approaching conchoidal. *Colour,* brass yellow, inclining sometimes to greenish yellow and steel gray. *Lustre* and *Transparency,* metallic, opaque. *Hardness* and *Frangibility:* brittle, but does not yield to the knife; scratches glass. This character distinguishes it from sulphuret of copper. *Powder,* brownish black. *Specific gravity,* 4·6 to 4·8. *Composition,* iron 47·85, sulphur 52·15. *Before the blow-pipe,* it melts, giving out a sulphureous odour, and leaving a blackish slag, which is magnetic. It is universally diffused.

SCHORL.

This mineral is met with amorphous, crystallized, and disseminated. It occurs in Cornwall, crystallized with quartz, in so large a proportion as to form one of the constituents of a rock, called schorl rock, which has the same geological relations as granite.

Form: the common form of the crystals is a prism of many sides, generally striated longitudinally, rarely terminated at each end by three planes: it occurs also as acicular crystals, parallel or divergent. *Colour,* black and brownish black. *Lustre* and *Transparency,* glistening, vitreous, opaque. *Hardness,* scratches, quartz. *Fracture* and *Frangibility*, fine grained, uneven, sometimes conchoidal, fragile. *Electricity*, becomes electric by being heated, and acquires polarity. *Specific gravity*, 3·2. *Before the blowpipe*, schorl fuses *alone*, with strong intumescence, and turns white; the intumesced portion afterwards melting with difficulty into a translucent grayish-yellow bead. With *borax*, it effervesces and melts into a clear glass with a tinge of iron. With *microcosmic salt*, it effervesces briskly, leaving a skeleton of silica. *Composition*, silica 38, alumina 34, magnesia 1, potassa 6, oxide of iron 21, and a trace of manganese.

Tourmaline is a finer variety, used in jewelry, of different colours, white, green, yellow, blue, and black; harder and more transparent than common schorl, melting before the blowpipe with greater difficulty, both with and without fluxes, and differing from it slightly in chemical composition. *Localities:* the village of Schorlaw in Saxony, where it was first found; also Bavaria, Bohemia, Switzerland, Spain, Hungary, Asia, and America. *British Localities:* Perthshire, Banffshire, Inverness-shire, and Argyleshire; near the Land's End in Cornwall; also in the tin veins, and disseminated in the granite rocks of that county; and in the granite of Wicklow and Dublin.

CHIASTOLITE.

Chiastolite occurs crystallized in the clay slates of Cumberland, Spain, Brittany, Ireland, and North America, sometimes in such large quantities as to become a constituent of the rock. It is a mineral about which little is known. We heard it thus described by Professer Sedgwick, in the Geological Section of the British Association at Dublin:—"That singular mineral, chiastolite, about which all I can tell you is, that I can call it by a hard name, and that I believe is as much as most of my neighbours can do." It is thus described and figured by Phillips:—"It has only been met with in slightly rhomboidal prisms, composed of two distinct substances. The exterior is grayish-white, the interior black or bluish-black, and its sides are perfectly parallel to those of the exterior substance, which in some specimens are so thin as to form a mere coating. From each of the angles of the interior prism there often proceeds a black line, which sometimes reaches the corresponding angles of the coating, but is sometimes terminated by a black rhomboidal prism, so that the chiastolite occasionally consists of five black rhomboidal prisms, communicating by black threads, and, as it were, imbedded in a grayish-white or reddish substance, which has a lamellar structure, is translucent, and hard enough to scratch

Chiastolite.

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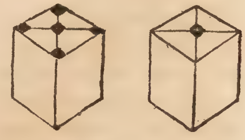


glass." *Composition:* Berzelius considers it a compound of silica and alumina. *Before the blowpipe,* the whitish part of the crystal is infusible, but assumes a whiter tint: a very thin cake made of the powdered mineral concretes into a mass. With *borax,* it melts with difficulty into a clear glass. It gives a blue colour with solution of cobalt. The black part yields a black glass without fluxes. *British Localities:* the Wolf Crag, near Keswick, and on Skiddaw, in Cumberland, in clay slate: at Aghavanagh and Baltinglass Hill, county of Wicklow, Ireland.

Garnet.

Garnets occur crystallized in granite, gneiss, mica, schist, clay slate, primary limestone, near basaltic dykes, and in veins. They sometimes occur in mica slate in such abundance as to equal in quantity the other ingredients of the rock enclosing them. In a bed of green talc, between Styria and Carinthia, the common garnet occurs in crystals of two pounds weight and upwards.

Form, a dodecaedron with rhomboidal planes, which is considered the primitive. It also occurs in crystals, having twenty-four rhomboidal faces. *Fracture,* conchoidal. *Colour,* yellowish, greenish, or blackish-brown. *Lustre,* vitreous, shining. *Transparency,* opaque, or only slightly translucent. This is the chief point in which common garnet differs from the mineral known as alamandine, or precious garnet. *Hardness,* scratches quartz with some difficulty. *Composition,* according to Vauquelin, silica 43·0, alumina 16·0, lime 20·0, oxide of iron 16·0. *Chemical Characters:* before the blowpipe, fuses to a black globule. Soluble partially or entirely in muriatic acid. The solution yields an abundant blue precipitate with ferro-prussiate of potassa—a white precipitate with oxalate of ammonia, and slight traces of alumina with ammonia. *British Localities:* in Cornwall of a red colour in small quantities, in schist and chlorite; north of Keswick, in Cumberland, in a porphyritic felspar; near Huntly in Scotland; in the counties of Wicklow and Donegal in Ireland in granite; in altered shale of the carboniferous limestone series by the side of a basaltic dike near Plas Newydd in Anglesey; and under similar circumstances in shale and limestone, altered by a basaltic dike in High Teesdale.

We shall conclude our description of simple minerals entering into the composition of rocks, by recommending the student who may not have the advantage of seeing museums and attending lectures, to purchase a named collection of the minerals we have described, which may be done at a trifling expense. We would urge him not only to look at them, but to try their external characters and habitudes before the blowpipe, comparing them with the descriptions. This will impress them on the memory much more than mere inspection. He will thus become familiar with them, and be able at once to recognise them when he finds them combined in rocks; and the habit of examination thus acquired will render it easy for him to discover, with the assistance of that little book which we have before recommended, those less abundant minerals not here described, some of which he will not fail to meet with the moment he begins to study geology, hammer in hand. In studying the external and chemical characters of minerals, it is best to commence on substances with the names and composition of which we are acquainted.

CHAPTER IX.

ORDER OF ARRANGEMENT OF THE MATERIALS COMPOSING THE CRUST OF THE EARTH.

The repeated changes of the earth's surface illustrated by a supposed case of a succession of Roman and other remains in England—solutions of continuity in the series of deposits—means by which the earth's structure is laid open to the depth of some miles.—Classification of rocks—stratified and unstratified rocks—columnar structure—fossiliferous and non-fossiliferous strata.—Explanation of terms—dip—strike—anticlinal and synclinal lines—conformable and unconformable position—the order of succession never inverted—thinning off of strata—denudation—overlap—outlier—faults.

Geology has been defined to be, in its most extended sense, the ancient natural history of the earth, and of the changes which have taken place in the organic and inorganic kingdoms of nature. It teaches us the materials of which the earth, to a certain depth, is composed, and the order in which they are arranged. We obtain this knowledge by means of observation, aided in some degree by inductive reasoning. We carry this inductive process further, and are enabled to discover the agencies which were employed in the formation of the crust of the earth, the convulsions and revolutions to which it has been subject, and the various races of beings which have successively inhabited its surface during a series of epochs of long-protracted duration.

The former part of the inquiry, namely, that which relates to the materials composing the earth's crust, and the order in which they are arranged, forms the practical and elementary part of geology; the latter, comprising its higher generalizations, may be called theoretical or speculative geology; but, conducted as this is at present, it must not be confounded with the speculations of the cosmogonists.

When we speak of the high antiquity of the globe, of extinct races of animals and plants, of central heat, and of change of climate, we are sometimes accused of indulging in reveries scarcely less visionary than those which we condemn in Burnet and Whiston, and the other writers of that school. There is, however, a wide difference between their speculations as to the mode in which the world was created, and the investigations of modern inductive geology respecting the changes which the surface has undergone since its creation, and we have as conclusive evidence of the disappearance of one race of animals and plants, and of their having been succeeded by others, as we have, independently of history, of the existence of the Egyptians, Greeks, or any other nation of antiquity.

Repeated changes of the earth's surface illustrated by supposed case of Roman and other remains in England.

History informs us that England was first inhabited by the Britons, and that it was successively conquered by the Romans, the Saxons, the Danes, and the Normans; and we find in our island coins, weapons, and other monuments of all these different nations, to confirm the accounts of history. But confined, as these remains are, to the superficial soil, and not unfrequently blended together, it would be difficult, in the absence of history or tradition, to disprove the assertion that these tribes were all contemporaneous inhabitants of the country, much less could we prove that a considerable length of time elapsed between their different immigrations. The case, however, would be different, should we find these remains arranged in the following manner:—Let us suppose that in a certain part of England, we will say its western coast, we should find the remains of a town, buried, like some villages on the coasts of Cornwall and Ireland, beneath heaps of blown sand, and that in this town were found inscriptions in the English language, and a series of coins from the time of Charles I. to the reign of Queen Anne. It would be a sound inference that this town had been inhabited by the English during the interval between those reigns, and that it was overwhelmed with sand during or immediately after the close of the latter reign. Let us suppose, again, that in excavating beneath the foundations of this town we should find the ruins of another, consisting of burned and blackened bricks and stones mixed with calcined human bones and fragments of burned timber, together with coins and medals, and the least perishable articles of dress and furniture, all exhibiting appearances of having passed through the fire; and let us suppose that the most ancient coins met with were of the reign of Henry VIII., and the most recent those of the early part of the reign of Charles I. We should conclude that this town had been burned during that reign, and that on its ruins had arisen another which had subsequently been covered by sand. Let us further suppose, that in sinking a well a bed of clay four or five feet thick should be met with beneath the ruins of the burned town; that this clay contained the remains of land animals, mixed with thin and fragile shells, such as those which inhabit fresh water, and which proved, on examination, to be identical in species with those still inhabiting lakes and stagnant pools in the neighbourhood. We could scarcely avoid the conclusion that a lake had formerly existed on this spot, which had either been laid dry by some natural process, or had been drained artificially, and that on its site had been founded the town which was burned in the reign of Charles I.

We will now suppose that in the immediate vicinity there was a volcano subject to periodical eruptions after intervals of repose of a few years' duration; that streams of lava had been seen to flow from it, and to cool into solid rock; that at other times fine ashes and scoriæ ejected from its crater, and mixed with water, had been seen to form mud, and to solidify into a rock of an earthy appearance, called volcanic tufa, while occasionally torrents of hot mud were known to have burst forth from the crater, and to have hardened into the same kind of tufa.

Let us suppose, likewise, that beds of lava might be traced from the side of this mountain till they were seen to run under the stratum of clay forming the bottom of the ancient lake, and that on sinking through the clay and lava another town should be met with in the same state as the cities of Pompeii and Herculaneum; we should conclude, though we had never heard of those cities, and of the mode of their destruction, that this town had been overwhelmed by an eruption of the neighbouring volcano, and that a lake had subsequently formed in a hollow on the surface of the lava. We will suppose that the implements and articles of dress and furniture found in this town were of a very different kind from those found in the former town, and that the inscriptions on the monuments and public works were in Latin instead of English; we should learn from these circumstances that the modern English were not the original inhabitants of the country, but that they had been preceded by another people of different language and manners, who had inhabited it for a considerable period. Triumphs, sacrifices, feasts, marriages, and funerals, represented on medals and on the basso relievos of the public buildings, would give some insight into the manners and customs of this ancient people. In some of the houses at Pompeii there were found not only carbonized almonds and chestnuts, but even moist olives preserved in a glass-case, a loaf of bread retaining its shape, and marked with the name of the baker, was found in one shop; and in that of an apothecary was discovered a box of pills, with a small cylindrical roll by its side, evidently prepared to be cut into pills. Now, if in our suppositious Roman town in England fruits of the same kind were found,—if apparatus for making wine and oil were common in the houses,—and if, from the suddenness of the catastrophe, the wine-press or the olive vat appeared to have been abandoned, on the approach of the lava, in the midst of one of these operations, it would be no visionary conclusion that during the Roman era the climate of England was warmer than at present, for the vine and the olive to bring their fruit to maturity, and to be cultivated for the purpose of making wine and oil; and we should thus learn another curious fact, that there had been a change of climate as well as a change of inhabitants.

Again, let us suppose this town to stand on a series of beds of marl and clay, alternating with beds of lava, and that the strata of marl and clay, besides shells such as inhabit shallow estuaries, contained human remains and works of art,—that in the upper strata were found coins and fragments of pottery, like those of the Roman, or third city from the surface,—and that the lower beds, besides the estuary shells, contained the bones of stags, and buffaloes, and the tusks of wild boars, together with the canoes, stone hatchets, flint arrow-heads, and other relics of a rude tribe of hunters; while towards the middle of the series were strata containing the mingled remains of the two people:—From the shells being marine, and of those genera and species that frequent brackish estuaries.—from their state of preservation,—and from their being found of every age from the young to that of full grown individuals, with every indication of their having lived and died on the spot, we should conclude that at some remote period these strata had formed the mud and sand at the bottom of an estuary, into which rivers had borne down the remains of animals inhabiting the neighbouring forests; that some of the human remains had been conveyed into it by the same means, and that others had become imbedded by the swamping of the canoes of the savage, or the stranding of the navies of the civilized people.

Now as men do not build cities beneath the waters, we must conclude that this estuary had been converted into dry land, before the foundation of the Roman city whose fate it was to be overwhelmed by a volcanic eruption, and the beds of lava alternating with the marine strata would convince us that the volcanic action must have been going on in the neighbourhood for a considerable period before this catastrophe.

We will now suppose a shaft to be sunk to a still greater depth, either in the prosecution of some mining operation, or to satisfy the curiosity excited by these wonderful discoveries, the more wonderful because no tradition existed of the island having had any other inhabitants than the nation at present possessing it; and we will suppose that this shaft, in its progress, passed through a series of strata containing no human remains or works of art, but abounding in marine shells, we should then have satisfactory evidence that the tribe of hunters whose weapons and canoes were the lowest human remains met with, were the first people who inhabited the neighbouring land. Should we arrive at a point where beds of lava no longer occurred, we should ascertain the period when this volcano broke out. We will suppose that the shells also change their character in the lower beds, and are no longer estuary shells, but of such kinds as are found in deep water, and that beds of sandstone and conglomerate, containing no organic remains, are found at greater depths; and, finally, that a mass of granite is penetrated in which the operations are carried for several hundred feet, until the great depth of the shaft renders it impossible to prosecute the work further. The phenomena which we have been supposing to be discovered would afford satisfactory evidence of the following changes as having taken place on this spot.

We should have, in the ascending order—

1. A sea too deep in this place to support animal life, and having a rocky bottom of granite. On this bottom were thrown down the detritus of projecting peaks of granite, affording materials for the conglomerates and sandstones.

2. The depths of this abyss are in this way gradually filled up till it is rendered habitable by molluscs frequenting deep water.

3. The process of filling up continues till this sea becomes a shallow estuary.

4. Volcanic action commences in the neighbourhood, and has continued in activity ever since. It was probably the means of elevating and laying dry parts of the bed of the sea, and of forming a continent or large island in the vicinity; for the remains of trees and of land animals are now found imbedded in the sedimentary deposits.

5. The neighbouring land is at length inhabited by a tribe of hunters, who continue to occupy it unmolested for some time, as their reliquiæ are the only human remains met with in a series of beds of considerable collective thickness.

6. The estuary becomes dry land; a nation in a more advanced stage of civilization colonizes the country, and builds a city, which, after the lapse of several generations, is buried beneath a torrent of lava.

7. A lake is formed in a hollow on the surface of this lava. It becomes filled up with sediment, or is drained artificially. A town is founded on its site, and is inhabited during the reigns of many kings by a race of people speaking the same language as the present inhabitants of the country.

8. This town is destroyed by fire, and another quickly springs up on its ruins, which is overwhelmed in its turn by heaps of blown sand.

In one respect we have followed the example of the cosmological writers; we have *assumed our data.* We have imagined active volcanoes in England, and have supposed them to have destroyed towns, after the manner of Herculaneum and Pompeii, which, as far as England is concerned, is a pure fiction. Neither is there known any locality in the world in which a similar succession of human fossil remains have been met with. In one place the remains of a town are found buried beneath sand; in another country a city, exactly in the state it was nearly two thousand years ago, has been preserved under a bed of lava. The skeletons, the rude weapons, and the canoes of the savage, have been found in the peat-moss and in the lacustrine strata of marl, or in the ancient estuary below the peat; but beneath these there has never been found any succession of aqueous strata alternating with beds of lava, and containing human remains. Something of the kind might perhaps be found, could we have access to the strata now forming in the Mediterranean, in the vicinity of active volcanoes, and of those countries which were among the earliest habitations of the human race; but such formations are yet submarine.

We have supposed the succession of strata containing human remains described above, for the purpose of illustrating the kind of evidence by which we obtain information as to the changes which the same part of the earth's surface has at different times undergone, and for the purpose of showing the means by which it is rendered evident that time, and a long lapse of time, must have been required for the formation of the fossiliferous strata constituting the earth's crust. By means of the series of strata containing human remains, which we have supposed to be arranged over one another (had any such series existed), we should be able to prove, though history were silent on the subject, that this island had been successively peopled by several nations of different languages, manners and customs. The data being given, the inferences would be conclusive. In the face of such a series, it would be the height of absurdity to assert that all those different nations inhabited England at the same time. In the above series, for England substitute our planet; for dead languages and extinct nations, substitute extinct races of animals; and for Britons, Romans, and Saxons, substitute the Mastodon and Dinotherium, the Ichthyosaurus and Iguanodon, the Ammonite and the Trilobite, and the data are given by which we prove the high antiquity of the globe. In the case of human reliquiæ the antiquary ascribes many centuries to the duration of a people from finding the coins of a long succession of kings, and as he has learned the average duration of a generation of men, he can with precision determine the length of time during which successive people and dynasties possessed any region of the earth where these remains are found. Now what coins and medals are to the antiquary, organic remains, imbedded in a vast series of strata, are to the geologist; a series so vast, that it furnishes him with proofs of the lapse of ages, during the progressive formation of the earth's crust, before which the centuries within which the remotest researches of the antiquary are limited sink into insignificance.

The duration of those ages the geologist is unable at present and perhaps never will be able, to define. One material element in the calculation is wanting, which it may never be in our power to obtain, namely, the average duration of the life of certain marine animals. Could we procure this information, we might arrive at an approximate knowledge of the duration of a geological epoch, that is to say, the time that elapsed during the formation of a given series of strata.

Thus, when we find a stratum only a few inches thick, containing a particular species of mollusc in every stage of its growth, all the shells appearing to have been quietly deposited in the sediment of the sea on the spot where they lived, without any bed either above or below for more than one hundred yards containing any of the same species, it appears an inevitable conclusion that the whole of the lifetime of that species of mollusc was occupied in the formation of these few inches of rock; and if we knew the duration of that life, we might form some conjecture as to the least time required for the formation of the many miles in thickness of the fossiliferous strata.

Solutions of Continuity in the series of Deposits.

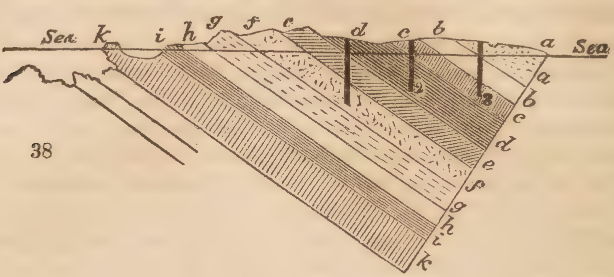
Had such a series of strata as we have been supposing to have been discovered in Britain ever existed there, we should have learned from it, without the aid of history, that the island had successively been peopled by the Britons, Romans, and English; and reasoning on that case alone, we should probably have come to the erroneous conclusion that they were the only people who had ever inhabited it, and that Henry the Eighth was the immediate successor of the last Roman emperor whose medals and coins were found in our imaginary English Pompeii. In this plausible error we might have remained until the chronological series was completed by such a discovery as the following:—Suppose, in some distant part of England, there were a conical hill, the sides of which were covered with ashes and scoriæ, and that there were a funnel-shaped cavity in the centre, from which might be traced beds of rock identical in character with the beds of lava of the active volcano; we should have evidence that this neighbourhood had formerly been the theatre of volcanic eruptions, which had ceased before the commencement of history or tradition; and if in the neighbourhood of this extinct volcano there were a series of alternating aqueous and igneous rocks, containing human remains, commencing with the British, continued through the Roman and Saxon, and terminating in the Danish era; and if in a third locality we should find a series commencing with the Saxons, and continued to the reign of Queen Elizabeth, we should be able, by combining these phepomena, to complete the chronological series. On the other hand, into what historical errors should we fall by confining our generalizations to any of these localities! So it is with geology. We imagine, after the careful examination of an extensive region of the earth, that we have completed the series of rocks, and that we have an unbroken record of the organic changes which have taken place upon our planet, from the epoch of its earliest habitable state to the present time; but no sooner have we arrived at this conclusion, than the study of some hitherto unexplored region convinces us that, in the district to which our observations had till then been confined, not only are certain terms of the series wanting in any given formation (by which is meant a group of rocks, having a certain general resemblance in the forms of their imbedded fossils,) but that a blank exists, in which the numerous terms of a new series must be introduced, connecting formations and systems of formation by that gradual transition from one animal form to another which prevails throughout nature, and the absence of which, in the case in question, ought to have warned us to suspect that a chasm existed which future observations in some other quarters of the world would hereafter fill up.

Some of these local violations of continuity will be noticed hereafter, when describing the several formations in detail. It was necessary to advert to the subject now, in pointing out the kind of evidence on which we found our generalizations respecting the lapse of time during which the world has been inhabited by animals, and respecting the organic and inorganic changes which have taken place upon its surface.

Means by which the Structure of the Earth is laid open to the depth of some miles.

There are many persons well informed respecting the figure of the earth, and its physical features, whose knowledge of its structure does not extend beyond the popular notion that it consists of a heterogeneous mass, in which sand, clay, gravel, and a variety of rocks are blended together, with no more regularity than the ingredients of a plum-pudding. They suppose that this was its original condition, and that the present physical features of the surface, its mountains, seas, lakes, and valleys, its rocks and its gravel, existed from the beginning as we see them now. It is even possible to make the circuit of the globe without obtaining more correct information on this subject, so long as our observations are confined to the surface only; but no sooner do we begin to penetrate below the surface, though our researches may be limited within a very narrow area, than new views open upon us. There are many districts in which it is impossible even to sink a well, or to open a quarry for the repair of the roads, without discovering that the rocks are arranged in layers, and succeed one another in regular order. Much valuable, but local, and unconnected information, was thus obtained by miners and others engaged in subterranean operations; and these details, extended, combined, and generalized by geologists, laid the foundation of our knowledge of the structure of the earth.

The depth, however, to which this structure is laid open by the hand of man, is extremely limited; the deepest mine in the world penetrates little more than half a mile below the surface, or about the eight-thousandth part of the distance from the surface to the centre of the globe. The convulsions which the crust of the earth has undergone have exposed its structure to a much greater depth.



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In cliffs on the sides of ravines, on the banks of rivers, and on the sea-shore, the strata may frequently be seen resting upon one another in an inclined position, as represented in the annexed diagram, fig. 38, their original horizontal state having been disturbed by a force acting from below. These natural sections often extend for many miles, and the inclination of the beds causes them to emerge successively to the surface, and enables us to estimate the perpendicular thickness *a x* of the whole series of beds from *a* to *k*.

Even in those cases where the succession of the strata is not exposed to view in natural sections, their inclined position renders it possible by several independent sinkings of no great depth, made at different points, 1, 2, 3, judiciously selected, to prove the order of succession of the different layers, whereas, had they remained horizontal, it would have been impossible to have ascertained this without sinking a shaft which would penetrate all the beds. By these means combined we obtain a knowledge of the structure of the earth to the depth of several miles, and over an extensive surface, and find that it consists of a great series of rocks arranged in regular order. The same kind of observations conducted in distant countries, demonstrate that similar series, maintaining an invariable order of succession, occur there also.

By extending these observations, we shall in time acquire an accurate knowledge of the geology of the entire globe. So far as these researches have hitherto gone, they show a remarkable identity in the older non-fossiliferous strata of the most distant regions. The fossiliferous rocks resting upon them are less uniform in their composition, so that in the series, *a*, *b*, *c*, we shall find, in one country, *b* consisting of limestone, in another of calcareous sandstone, in a third of shale, and in a fourth of siliceous rock; but under all these altered aspects, its identity may be ascertained by its organic remains, taken as a group, and by its position with respect to the strata, a and c, above and below it.

In some cases we may travel along the upturned edge of a stratum for a considerable distance, so as to remove all doubts of its identity, and thus obtain ocular demonstration of the gradual change in its mineral character, the organic remains continuing the same. In other cases, where we have not this opportunity of observing the gradual change in composition, we infer the place in the series of two rocks at a distance from one another, and of a different mineral character, by the identity, as groups, of the organic remains of those two strata, and not only of those two, but also of those above and below them in each locality.

The information thus obtained, we represent on plans and in sections. A section shows the strata as they succeed each other in the earth, and it supposes a cutting of them in the same manner that, by cutting an onion, we show the different coats of which it is composed. All sections, when the contrary is not expressed, are supposed to be made perpendicular to a horizontal plane. In a plan, we lay down on a horizontal plane the superficial area occupied by each bed, as it rises to the surface, or, in the language of miners, *bassets* or *crops out.*

We trace and delineate the superficial boundaries of strata, by travelling across their basset edges, in a number of parallel lines, noting on an accurate map of the country, the several points at which we pass from one kind of rock to another. Thus in the annexed diagram, fig. 39, in crossing the country intended to be represented by it in the line A B, A being supposed to be situated on sandstone, we should pass at a from sandstone to limestone, at b from limestone to slate, at c from slate to granite, at d from granite to slate again, at e from slate to limestone, at f from limestone to sandstone; and in traversing the same district along the lines C D and E F, we should find these changes take place at the points $a'\ b'\ c'\ d'\ e'\ f'$ and $a''\ b''\ c''\ d''\ e''\ f''$ respectively. In this way we construct geological maps, distinguishing by different colours the surface occupied by each kind of rock.

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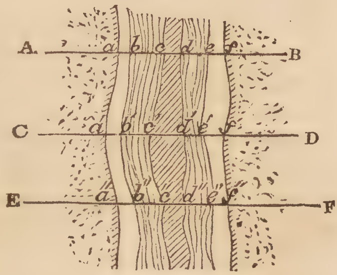

In speaking of a portion of the surface being occupied by any given rock, it must be observed, that over the greater part of the earth is spread a loose irregular covering of sand and gravel, not forming a component member of the series of rocks. Some of this gravel has been formed by atmospheric action, some may have been caused by local debacles or torrents, by the bursting of lakes, and by rivers having changed their beds; some may have been shot off the flanks of the nearest mountains during some period of elevation; but the greater part of it, in these islands at least, we consider to have been brought together by that great diluvial drift from the north, to which we have already alluded, and shall hereafter revert. In geological maps and sections, this loose covering is disregarded, and is not laid down, unless attended with some remarkable peculiarities, which render it desirable to mark the spot where they occur, and that rock which lies immediately below it, is considered as rising to the surface.

We must here observe, that the term rock, is applied by geologists, not only to those hard stony masses commonly so called, but to clay, soft sandstone, and even to beds of incoherent sand, provided they constitute members of a series of strata or beds.

Classification of Rocks. Stratified and Unstratified Rocks.

Having ascertained that the crust of the earth consists of a great succession of rocks, laid one upon another in a certain order, our next endeavour is to classify them, or to arrange in groups those rocks between which the closest analogies exist, in order to aid the memory, embarrassed among the almost endless details of the numerous alternations of calcareous, argillaceous, and siliceous strata, of which the series consists.

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In entering upon this task we soon discover a natural and obvious division of them into the *stratified* and *unstratified*, a division founded on the appearances under which they present themselves to our observation as masses. A stratified rock is one whose bounding surfaces are parallel, or nearly parallel, for great distances, thus including a layer, or tabular mass, which is called a stratum or bed; and a number of these strata, possessing a common character, is called *a formation*; thus we speak of the chalk formation, the lias formation, the carboniferous formation. These beds may be either horizontal, fig. 40, or vertical, or curved and contorted as in figs. 42, 44, 45, 46.

Jointed and Columnar Structure.

In an unstratified rock, there is none of this parallelism of bounding surfaces and division into tabular masses, continued for great distances. They usually present a rude amorphous appearance of irregular hummocks, but they are sometimes divided by vertical and horizontal joints into blocks of a regular shape, the most common form of which is that of a prism having a rectangular base. This is frequently the case with granite. When the breadth of these blocks is considerable in proportion to their height, they often assume the appearance of beds, and the rocks in which they occur, have been in consequence mistaken for stratified rocks; but this kind of structure may be distinguished from true stratification by the comparatively small spaces over which the parallel bounding surfaces of these false beds extend, and by the absence of bands, or thin beds of rock, of a different composition from the rest of the mass alternating with these pseudo-strata. When the height of the blocks is considerably greater than their breadth, the rock in which they occur is said to have *a columnar* structure, a structure very common in basalt, porphyry, and greenstone.

Sometimes these columns are continuous from the top to the bottom of the mass, in other cases they are jointed, and consist of a number of short prisms placed upon one another, fig. 41. This is the structure of the basaltic columns of the Giant's Causeway, where the prisms are in general hexagonal, though some occur with three, four, five, and eight sides. Quadrangular prisms are, however, the most common in rocks possessing the columnar structure.

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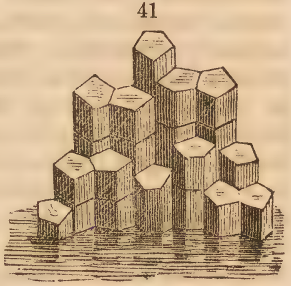


Another natural division of rocks founded on the mode of aggregation of their component parts, is into crystalline and sedimentary. Crystalline rocks are composed of one or more crystallized minerals, which must have been generated by chemical agency in the mass in which they occur, either from a state of fluidity, or under the influence of heat or electricity. Sedimentary rocks, on the contrary, consist of abraded fragments of older rocks in various states of attrition, brought together by mechanical agency, that is, by the moving power of water. Granite, mica, schist, porphyry, basalt, and lava, are crystalline rocks; chalk, shale, sandstone, and conglomerates, are sedimentary in their origin. Rocks again are divided, according to the agencies employed in their formation, into two classes, the aqueous and the igneous.

The boundaries of these divisions into stratified and unstratified, crystalline and sedimentary, igneous and aqueous rocks, coincide to a certain extent, though not entirely. All the igneous rock,s for instance, are unstratified; but there are some rocks of undoubted igneous origin, which are not crystalline: there are, again, some limestones of aqueous origin, which are both crystalline and stratified; some of the lower stratified rocks are of a decided crystalline character, but their origin is involved in much obscurity; on the one hand, they graduate into rocks which appear to have been formed by igneous action, and on the other, into rocks which are decidedly fragmentary, and of aqueous formation; and there are again other rocks, which, even in hand-specimens, exhibit a blending of the crystalline and mechanical structure.

Fossiliferous and Non-Fossiliferous Strata.

As rocks in general admit of a natural classification into the stratified and unstratified, so they admit of another equally natural division, into the fossiliferous and non-fossiliferous. Fossiliferous rocks are those which, taken as a whole, contain organic remains; we say taken as a whole, for strata, though devoid of fossils, are classed among the fossiliferous series, if they alternate with beds which contain them. In forming the subordinate groups, no one principle is applicable to the whole series. The unstratified rocks consist of a few simple minerals, quartz, felspar, augite, hornblende, mica, chlorite, talc, diallage, and serpentine, variously combined; they rarely, if ever, contain organic remains; they occur in irregular masses beneath the other strata, or protruding through them, or traversing them vertically, as dikes or veins; they have no constant relation to one another, or to the stratified rocks; it is impossible, therefore, to reduce them to a series, or to arrange them in chronological order, except in those cases where they occur associated with stratified rocks, whose relative position, and consequent age, is known. The unstratified rocks, therefore, only admit of a mineralogical classification, and many of them pass so insensibly into one another, by the absence of one particular mineral, and the presence of another, that it is a matter of no small difficulty to frame a definite nomenclature for all those compounds; and it is frequently better to describe their composition than to attempt to give them names. The same remark applies to the non-fossiliferous strata, which are so closely allied in composition to some of the igneous rocks. They admit of no other arrangement than one founded on their mineral character; they can scarcely be said to have any regular order, though, on the whole, the compounds called gneiss and mica slate occupy the lower parts.

On the other hand, a mineralogical classification is inapplicable to the fossiliferous rocks. Notwithstanding their great variety of colours, and degrees of hardness, they can only be viewed, when considered mineralogically, as a series of clays, sandstones, and limestones, repeated again and again. We have, for instance, frequent alternations of calcareous strata with shales and sandstones in the carboniferous series, with clay and sand in the oolitic, cretaceous, and tertiary systems; and there is without doubt, a certain general difference between the limestones of these different eras: but, on the other hand, as we have before remarked, the mineral composition of groups or particular beds, is only characteristic of small areas. The carboniferous limestones of the southern parts of England, in which limestone is the prevailing rock, and coal does not occur, passes, in the north of England, into a series of shales, sandstones, and beds of coal, and the limestone becomes a subordinate member. So, also, the oolite of the southwest of England consists chiefly of calcareous strata, abounding in marine exuviæ. In Yorkshire it is represented by beds of sandstone and shale, associated with an inferior kind of coal or lignite, the organic remains are chiefly those of land plants, and the marine remains are by no means numerous. The representatives of these strata among the Alps (the lower part of the Jura limestone) consist of indurated rocks, so closely resembling the calcareous parts of the slate series, that they were for a long time confounded with them, and their real age was only discovered by the examinations of their organic remains.

The cretaceous rocks are a family of extensive distribution in Europe, and are among the most persistent in their mineral character over large areas. The white chalk of the British islands prevails over a large part of France and Germany, and occurs in Poland, Sweden, and Prussia; but in the Alps, the rocks of this age (the upper part of the Jura limestone), as characterized by organic remains, consist of compact limestones and sandstones, equal in hardness to those of the older formations.

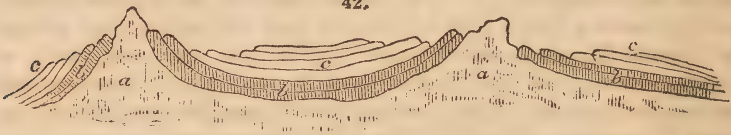
In the Pyrenees and Spain, according to Mr. Lyell, the rocks of the same era are represented by compact and crystalline marbles, conglomerates, red sandstone, and thin shales and grits containing fossils which are characteristic of the chalk in other parts of Europe. So again among the strata above the chalk, rocks occur which possess precisely the mineral composition which was at one time deemed characteristic of older formations. There are tertiary limestones which, except by their fossils, cannot be distinguished, particularly in hand-specimens, from chalk and oolite, and there are tertiary arenaceous deposits, which might be mistaken for the new red sandstone.

Brine-springs and beds of rock-salt were formerly considered characteristic of that formation; but in Spain they occur among the rocks of the age of our chalk, and in Poland in tertiary strata. The fossiliferous strata, therefore, must be classified according to the organic remains contained in them; and when we say that a given order of succession prevails among the stratified rocks, we mean that certain systems of strata, that is, of mineral substances, no matter of what kind, have been successively deposited at different distant epochs, and that in those countries the structure of which has hitherto been most examined, they contain, certain general assemblages of fossils which are not to be found in the strata above or below them.

Explanation of Terms. Dip.

We have spoken of the inclined position of the stratified rocks as affording us an insight into the structure of the earth, to a greater depth than would otherwise have been accessible to us. This, though evidently not their original condition, is that under which they are most commonly found. There is abundant evidence that they were deposited by water, that each of them successively formed the nearly level bed of the ocean, and consequently that, however inclined they may be now, they once must have been horizontal, in which state they may now occasionally be seen, though in most cases they deviate more or less from the horizontal position, are sometimes found highly inclined, or quite vertical, and often bent or contorted. They are always found to have the greatest inclination in the vicinity of masses of unstratified rocks.

42.



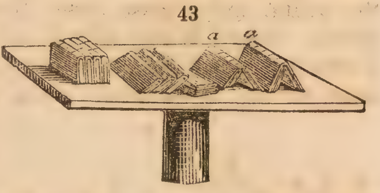
The centre of a chain of mountains consists in general of a mass of granite or unstratified rock, on either side of which are found the stratified rocks, highly inclined, the non-fossiliferous strata being nearest to the unstratified rocks, and the fossiliferous strata succeeding them in that order which has been found, on the evidence of organic remains, to be invariable among them, so that the same series of beds is repeated in the same manner on each side of the chain, as in fig. 42, where *a* represents the unstratified rocks, *b* the non-fossiliferous strata, and *c* the fossiliferous. As the strata recede from the mountains, they become more horizontal, till in the plains they deviate very little from that position.

This inclination of strata is called their *Dip*, the amount of which is expressed by the angle it makes with an horizontal plane, and its direction by the point of the compass to which the strata decline.

Strike.

The *Strike*, or direction of a bed, is a line at right angles to its dip. If we place on a table a number of books, laid one on another, supported by another book, the table will represent the horizontal plane, and the angle which the tilted books make with the table, will be the angle of their dip; that is, the more upright the books, the greater the dip, and the less they were tilted, the less the angle of the dip. The strike, or direction, again, would be represented by the lines of the backs of the books. If the books dipped towards the north and south, their strike would be east and west; if they dipped either to the east or the west, their strike would be north and south. Having found the dip of a stratum, or series of strata, we know the direction of the strike; but the converse will not hold good; the dip cannot be deduced from the strike, since there are two lines of dip common to each line of strike, and strata having a north and south strike, may dip either to the east or west.

43



In traversing the north of England, from west to east, we find the stratified rocks dipping from the Cumbrian chain westward to the Irish Sea, and eastward to the German Ocean, and the strata of the east of England pass under the sea, and rise again on the Continent with an inverted dip against the slopes of the next chain of mountains.

The surface of the earth may thus be considered as a series of basins filled with stratified rocks, and bounded by masses of unstratified rocks; the strata being horizontal or nearly so towards their centres.

Anticlinal and Synclinal Lines.

That line in a chain of hills or a valley from which the strata dip in two opposite directions, is called an *Anticlinal Line*, or axis. If a book be placed half open on its edges, like the roof of a house (*a*, fig. 43), the line of the back of the book will represent an anticlinal line, and the leaves will represent the strata dipping in opposite directions, and the line along which the edge of the book meets the edge of another book placed parallel to it, will represent what is called a *Synclinal* line, namely, that along which the strata dip towards each other. Anticlinal, as well as synclinal lines, may run either along the ridge of a hill, or the bottom of a valley, as shown in the annexed diagram, where *a a* represent anticlinal lines, on the summits of hills, and *a′* an anticlinal line in a valley, in neither of which cases has the unstratified rock below been forced through the stratified rock as at *a″*. At *b* is a synclinal line running along the bottom of a valley, and *b′ b′* are synclinal lines on hills.

In some cases, a country is traversed by a series of anticlinal lines running parallel with each other for a considerable distance. In other cases, one set of anticlinal lines is crossed by others having different directions. The broken and confused state of the strata, under these latter circumstances, may easily be imagined. North Wales affords instances of both these conditions. From the Menai Straits to near the English border, the anticlinal lines having a direction about E.N.E., and W.S.W., succeed one another with the greatest regularity of parallelism, and often within less than three miles of one another, so that fig. 44 nearly represents the state of the strata in the Cambrian range; but east of the Berwens these are crossed by other anticlinal lines, having a different direction, which have broken the strata up in all directions, and have given to them the appearance of the waves of a troubled sea.

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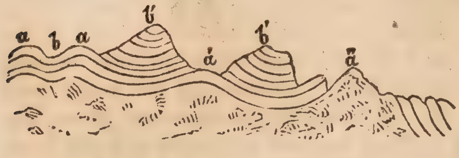

Conformable and Unconformable Position.

When the planes of strata are parallel to one another, like the books of each series in fig. 43, they are said to be conformable; no matter whether their position be horizontal, vertical, or of any intermediate degree of elevation; but it has frequently happened that, after one set of strata were deposited, they have been tilted, and another set have been deposited horizontally, either upon their upturned edges, or abutting against them, in both of which cases the two sets of strata are said to be unconformable.

So in fig. 45 the beds of the series *a* are conformable to one another, but are unconformable to those of the series *b*. It may be observed here, that by means of this unconformable position of some strata in certain localities, we learn that all the chains of mountains in the world were not of contemporaneous origin, but have been upheaved at several successive epochs. Thus, if on the flanks of one chain we find a series of strata *a*, fig. 45, tilted and covered unconformably by another set *b*, it is obvious that the chain must have been thrown up after *a* was deposited, but before the formation of the series *b*; and if, on the flanks of another chain, the series *a* and *b* are both found tilted and covered unconformably by another set *c*, fig. 46, we have evidence that this

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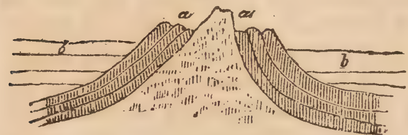
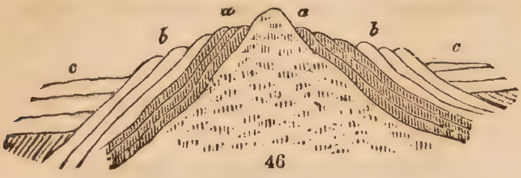


chain of mountains is of more recent origin than that on the flanks of which the strata *b* are undisturbed.



46

Order of Succession never inverted.

We have spoken of the strata having an invariable order of succession, which order is never inverted, so that in the series *a b c d*, *a b* and *c* are never found below *d*, nor *a* and *b* below *c*, nor *a* below *b*; and when the sequence is not broken, *c* always rests on *d*, *b* on *c*, and *a* on *b*. It must not, however, be supposed that this last is always the case; for, as we have already hinted, there have been many breaches of continuity in the order of succession, so that between two given strata not only is another stratum wanting, but in some cases a whole system of strata, which are found between those two beds in other localities. This may have arisen from two causes; either the missing beds may never have been formed on that spot, or after they were formed, they have been removed, or *denuded*, as it is called by the abrading action of water, before the newer strata were deposited.

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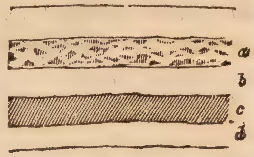
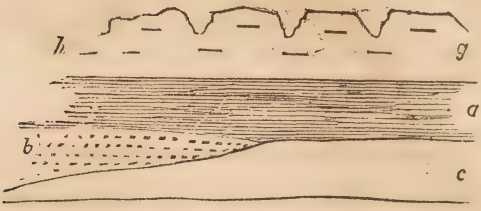


Thinning off of Strata.

In cases where the strata rest unconformably on one another, as in fig. 46, very modern beds may be in contact with very ancient beds; and if we assume for the present what we shall hereafter produce evidence to prove, that the stratified rocks have been formed beneath the bed of the sea, and upraised by the unstratified rocks bursting out from below, and that there have been subsidences and re-elevations of parts of the earth's crust, we can readily account for the intermediate parts of the series not having been formed on that spot. The forces which tilted the older strata may have raised them above the surface of the sea; after remaining in that state for some time, they may have been again submerged. But in cases where there has been none of this violent disturbance, but the strata are conformable, we sometimes find a particular bed gradually diminishing in thickness, or *thinning off*, as it is termed, till it is lost entirely, as in the annexed diagram, fig. 48, and *a* is seen resting conformably on *c* at *g*, while, at *h*, *b* is largely developed, and *a b c* succeed each other in regular order. This very frequently happens with a single bed of a series, or formation, and sometimes with a whole formation.

48

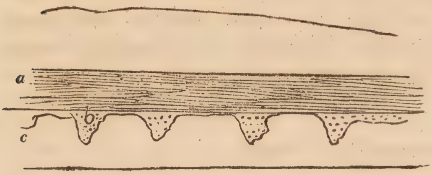


No sets of strata are universally continuous; there are no universally stratified rocks, though certain groups of them are found over such extensive areas as to lead to the conclusion that they were formed by very extensive and uniform causes. In general, the older the formation the greater is its extent.

Denudation.

In other cases, where two beds rest conformably on one another, and the upper surface of the lower bed *c* has been water-worn, as in fig. 49, before the upper one *b* was deposited, an intermediate bed or beds may have been formed on this spot, and subsequently removed by denudation. We have sometimes direct evidence of this, when we find *a* and *c* in contact, the sole remains of *b* being the portions lodged in the hollows in the surface of *c*, which thus escaped the abrading action which removed the rest of the bed.

49



Overlap and Outlier.

Figure 50 represents a section extending over several miles, and exhibits an instance of an *Overlap*, and an *Outlier*. In this section *e* and *e'* were once continuous portions of the same bed, which rested on, and extended over, the edges of *a b c*. The portion of this overlapping bed, which connected *e* and *e'*, having been removed by denudation, which also cut into the beds beneath, the deceptive appearance is produced of *e* having immediately succeeded *a*, whereas its real place in the series is after *d*. Insulated portions of a bed, or formation, like *e*, separated from the main body to which they belonged, are termed *outliers*.

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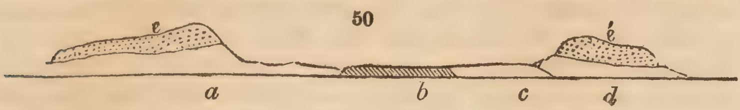
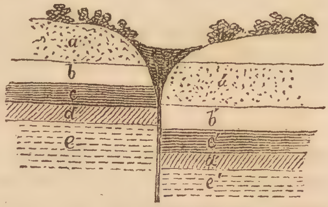


Faults.

51



The continuity of a stratum in the same plane is frequently broken by fissures or dislocations, termed by miners, Faults, as represented in the annexed diagram, fig. 51. The strata at *a a'*, *b b'*, &c., were once continuous, but by a subsidence of the portion of rock on one side of the line of fault, or by an elevation of that on the other side, the beds became displaced, so that *a'* is several feet lower than *a*, and abuts against the fractured ends of *b* and *c*, while *b'* abuts against *d*. These fissures are sometimes a mere line, sometimes they are many feet in width, and are filled with clay or loose stones. They occasion great trouble and inconvenience in collieries, by cutting off the beds of coal, and rendering it necessary to search for them in a different plane; but they are accompanied by countervailing advantages. In the first place, they counteract the tendency of the beds arising from their inclined position, to plunge their lower ends to a depth that would be inaccessible but for these faults, which divide a bed of coal into several tables or stages elevated one above another, (fig. 52,) and so kept nearer the surface than they otherwise would be. And secondly, when filled with clay, as they often are, they perform another still more important office, by dividing a coal-field into a number of insulated sheets of rock, by dams impervious to water, and thus preventing its access in quantities which would be beyond the control of the most powerful machinery; and this would be the case had the beds of coal, and of grit and shale interstratified with them, remained continuously united.

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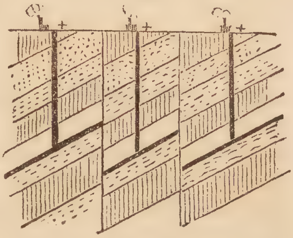

The displacement of the beds on either side of a fault, does not, in general, amount to many feet; but it is sometimes on so large a scale as to occasion inequalities on the surface, which rank as

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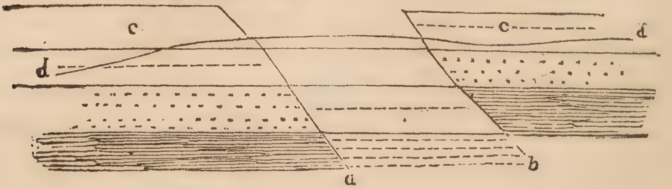
mountains. The Penine chain in the north of England, is caused by an enormous fault running north and south, which has thrown down the strata on its western side more than a thousand yards. Surface inequalities like this, however, are not always produced by faults, for in the Newcastle and other coal-fields, where the amount of displacement is accurately ascertained by numerous mining operations, and frequently amounts to 500, and even 800 feet, the uplifted portions (*c c*, fig. 53) of strata which would have formed steep escarpments have been removed by denudation, and planed down, as it were, to the general level *d d*.

53



Faults are vertical, as in figs. 51, 52, or they deviate from the perpendicular, as in fig. 53, in which case they are said to have an underlay. It is a general rule, that the depressed strata are found on the side to which the fault dips, as in the case *a*, fig. 53. The opposite case, in which they are elevated on the side of the underlay, as in *b*, is very rare.

CHAPTER X.

Unstratified rocks—granite—syenite—greenstone—hypersthene rock—serpentine and diallage rock—basalt—porphyry—volcanic rocks.—Stratified rocks—origin of their division into primary, transition, secondary, and tertiary.—Primary or non-fossiliferous strata—gneiss—mica slate—chlorite slate—talcose slate—hornblende slate—quartz rock—argillaceous schist—crystalline limestone—geographical distribution of the primary strata—Wernerian and Huttonian controversy respecting their origin.—Fossiliferous strata—William Smith—strata identified by their organic remains—groups of organic remains—the English order of succession, applicable to the rest of Europe.—The great divisions of primary, secondary, and tertiary rocks, are found in all countries yet explored.

UNSTRATIFIED ROCKS.

The unstratified rocks are Granite, Syenite, Greenstone, Hypersthene rock, Diallage rock, Serpentine, Basalt, Claystone and Claystone-porphyry, Clinkstone and Clinkstone-porphyry, Compact Felspar and Felspar-porphyry, Pitchstone and Pitchstone-porphyry,—and the volcanic rocks, Trachytic, Basaltic, and Graystone Lavas, Obsidian, and Pumice.

Granite.

Granite is a compound crystalline rock. The minerals which enter into its composition are quartz, felspar, mica and hornblende, united in variable proportions; but it is not essential that they should all be present. The rock usually denominated granite consists of quartz, felspar, and mica, with occasionally the addition of hornblende. Sometimes this mineral prevails to the exclusion of the mica, and the granite passes into a rock called syenite. By the prevalence of hornblende and felspar, it passes, in a similar manner, into greenstone. If mica and quartz predominate, it passes into mica slate, one of the non-fossiliferous stratified rocks. To all these compounds of two or more of the four minerals we have enumerated, many geologists, following the nomenclature of Dr. M'Culloch, have applied the name of granite; but it cannot be used with propriety with respect to such rocks, unless where they are clearly subordinate to large masses of well-defined granite, and arise from accidental variations in the proportions of the ingredients, prevailing only over very limited spaces. Besides the four minerals above enumerated, others occasionally enter into the composition of granite. These are, chlorite, talc, actinolite, steatite, and compact felspar. But granites in which these form integrant parts of the mixture, are comparatively rare. Granite most commonly occurs in masses continuous over a great space, and having no determinate shape. These are frequently traversed by joints and fissures, which sometimes divide the rock into tabular masses, having the false appearance of stratification, sometimes give it a columnar structure, noticed at fig. 41. The texture is, as we have before observed, confusedly crystallized, the crystals interfering with one another's forms, and giving the rock a granular appearance. The magnitude of the parts is various; sometimes each particular mineral exceeds an inch in diameter, in other cases they are so minute as scarcely to be visible.

Graphic granite, which occurs chiefly in veins, consists of quartz and felspar alone, crystallized in prisms, the cross section of which gives rise to an appearance somewhat resembling Hebrew characters, whence its name.

Granite frequently assumes a porphyritic texture, that is to say, distinct crystals of felspar are imbedded in a granular base, of which felspar confusedly crystallized forms one of the ingredients. Examples of porphyritic granite from Cornwall are very abundant in the slabs with which the footpaths of the streets of London are paved.

The colour of a rock consisting of several minerals blended in different proportions, and varying themselves in their colour, must of course be very variable. The mineral which generally predominates, and determines the colour of granite, is felspar, which is most commonly dark red or white; but it occasionlly occurs of other hues, as ochre-yellow, pale and dark gray, and, rarely, green. Quartz, the most abundant ingredient next to felspar, is usually white or watery, sometimes gray, or nearly black, and has a large share in regulating the colour of the rock. An abundance of hornblende, which is always black or dark green, produces a rock varying from dark gray to black. The same effect is produced by mica when black; but as it is also white and brown, it occasions corresponding differences in the colour of the compound. It is almost needless, therefore, to add, respecting the colour of granite, that it is of various hues,—red, white, black, and gray,—the most common being white and dark red. Granite occurs as the fundamental rock on which all the other known rocks rest, though it is evident that the substances which afford the materials of the trap and volcanic rocks ejected to the surface are deeply seated below the granite.

Granite also occurs as beds of irregular shape, interposed among the strata of gneiss, and the other older stratified rocks. It is likewise met with in contact both with the ancient and modern strata in uplifted masses, which appear to have been consolidated before their elevation.

Another form in which granite occurs is as veins ramifying into the adjacent rocks, as in fig. 54, which represents the veins shooting from the granite through gneiss, at Cape Wrath, in Scotland; and they have been observed intersecting mica schist, claystone, and limestone, in numerous other localities. Granite itself is frequently traversed by veins of granite of a different colour and mineral composition; and there are instances near Heidelberg in which three sets of granite veins, of three different ages, all differing in colour, grain, and peculiarities of mineral composition, intersect each other. Dikes may be considered veins on a larger scale, the chief difference being that dikes are of greater width, and have their sides parallel for greater distances; whereas veins branch out, and thin away into fine threads. Dike is the provincial name in the north of England for a wall, and is applied to large veins of igneous rocks, which traverse other rocks, because, being harder than the rest of the mass, they are less liable to decomposition, and project in relief, having the appearance of a wall. Granite is traversed by dikes as well as veins; and these have sometimes broken through the stratified rocks of different ages, and have covered them as irregular overlying masses. The most recent rock found in Europe into which granite has been observed to intrude, is a rock of the age of the chalk in the hill of St. Martin, near St. Paul de Fenouillet, in the Pyrenees, described by M. Dufrénoy. Syenite, a rock closely allied to granite, has been found overlying the chalk at Weinbohla, near Meissen, by Professor Weiss, and by Mr. Griffith, at West Tor, near Fair Head, in the county of Antrim.

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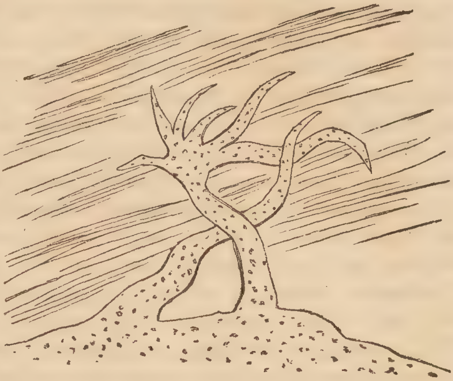

According to Mr. C. Darwin, the granite of the Cordilleras, in South America, has been in a fluid state since the tertiary era, and has altered and contorted strata of that age.

The origin of granite was a subject of much controversy, within the last half century, between the followers of Werner and of Hutton, the former maintaining that it had been deposited from a state of aqueous solution, the latter that it had crystallized from a state of fusion. The igneous origin of granite is now generally admitted. The following are the proofs of this origin.

It graduates in mineral composition through syenite and greenstone into basalt, and other rocks of the trap family, which are not to be distinguished from those rocks which we see poured forth from modern volcanos; and the effects produced by granite and the trap rocks on the sedimentary strata with which they come in contact, are precisely the same as those produced, under similar circumstances, by the volcanic rocks. Among others, they convert beds of coal traversed by them into coke and anthracite; and in the same manner that beds of lava are traversed by dikes and veins of more recent lava, so is granite traversed by dikes and veins of granite more recent than itself. Additional proofs of the igneous origin of some of those trap rocks into which granite passes by insensible gradation, were furnished by the experiments of Mr. Gregory Watt and Sir James Hall. The former, on fusing basalt, found, that if suddenly cooled, it formed a vitreous mass, if allowed to cool slowly, it returned to its original stony character and prismatic structure. Sir James Hall produced artificial crystalline rocks by submitting their pounded ingredients to strong heat under pressure.

Professor Mitscherlich, as we have before observed, formed artificial crystals of augite, which is closely allied to hornblende, one of the constituents of granite, by the fusion of definite proportions of the earths which enter into its composition; and though all efforts to produce artificial crystals of felspar have hitherto failed, they have been found on the walls of a furnace in which copper slate and copper ore had been smelted.

Syenite.

This rock consists of compact or crystallized felspar, united with hornblende and quartz. The name is derived from Syene, in Upper Egypt, where it abounds. It occurs in overlying masses and dikes.

Greenstone.

The components of greenstone are compact or crystallized (sometimes vitreous) felspar, and hornblende or augite, the texture varying from largely granular to almost earthy. When the felspar is crystallized, it is not easy to distinguish greenstone from syenite. Most writers make the difference between these rocks to consist in colour, giving the name of syenite to those compounds which are red, pale white, and yellow, and that of greenstone to those which are gray or greenish. The two colours may frequently be seen in the same block and even hand-specimen. Ingenious advantage has been taken of this transition from greenstone to syenite in the formation of a colossal Egyptian statue in the British Museum, the body of which is greenstone, and the head (part of the same block) is composed of red felspar, through which crystals of hornblende are dispersed.

A better distinction than that derived from the colour of the felspar appears to be founded on the proportions of the ingredients; those in which the felspar prevails being classed as syenites, and those in which the hornblende, or augite, predominates, as greenstones. The compounds of common felspar and augite are called augitic greenstones.

The augite rock of Dr. M'Culloch consists of compact felspar and augite. Greenstone sometimes contains cavities filled with almond-shaped nodules of agate, calcedony, or carbonate of lime. These varieties are termed amygdaloid. Greenstone occurs in dikes, and in interposed and overlying masses, and has frequently a columnar structure.

HYPERSTHENE ROCK.

The felspar is compact or crystallized, generally common, but sometimes vitreous, of a white or red colour. It occurs sometimes in dikes, but more commonly in uplifted masses associated with granite.

SERPENTINE AND DIALLAGE ROCK.

Both common and noble serpentine are considered, when pure, as simple minerals, and in that state form considerable masses, but they are generallly more or less mixed with diallage. Diallage rock consist of diallage and compact felspar. Both these rocks occur blended with greenstone, into which they gradually pass. The varieties of serpentine enumerated by Dr. M'Culloch, are—

1. Common Serpentine. i. With an earthy and uniform fracture. ii. With a splintering fracture passing into conchoidal. iii. With a splintering fracture passing into granular. iv. With a granular fracture, softer and becoming sectile, the potstone of some mineralogists. v. Passing into indurated talc a variety of talcose schist, the potstone of others.

2. Noble Serpentine, with a foliated and splintering fracture, conchoidal or splintering conchoidal. They occur in dikes and masses, also interposed among the primary strata, resembling the irregular beds of limestone occurring in similar situations, also in overlying masses. Instances are mentioned by Dr. M'Culloch, in which dikes of greenstone passing through limestone change into serpentine when they come in contact with the limestone.

BASALT.

This is a term which has been applied in a very vague manner. Any dark-coloured rock having a columnar structure was for a long time called basalt; thus columnar claystone, clinkstone, compact felspar, and greenstone, were all confounded under this name, or the still more indefinite term, trap. The latter word is derived from the miners of Sweden, in the language of which country *trappa* signifies a step or stair, and was applied to these rocks on account of their occurrence in large tabular masses, rising one above another like a flight of stairs. The columnar structure has long been abandoned as a distinctive character of basalt, and the term is now limited to a dense compact mass of hornblende or augite, in which crystals of felspar are visible, and which contains titaniferous iron. As the felspar increases in quantity, and the hornblende or augite becomes coarser grained, it passes into greenstone; those basalts which are composed of augite and felspar, are sometimes called dolerites.

The aqueous origin of basalt was as fiercely maintained by the Wernerians as that of granite. It was in fact the weakest point of their position; for let basalt be admitted to be an igneous rock, and it was difficult, if not impossible, to ascribe an aqueous origin to the varieties of greenstone and syenite through which it passes by insensible gradations into granite.

Basalt is now admitted to be a pyrogenous rock by all geologists, even by those who, in the early part of their career, were most deeply imbued with the Wernerian doctrines. It is scarcely thirty years since Dr. Buckland and Mr. Conybeare went to the county of Antrim to collect proofs of the aqueous origin of basalt, and they came back proclaiming it to be an igneous rock. They saw the changes produced by it on the sedimentary rocks.

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They saw chalk converted at the point of contact into crystalline limestone, in the same manner that in the experiments of Sir James Hall powdered oyster-shells were converted into marble by heat under pressure; they saw coal converted by it into coke and cinders, and they were convinced. The igneous origin of basalt was never questioned by those geologists who had opportunities of studying nature in countries which are the seats of active volcanos. The varieties of lava termed augitic are not, in point of fact, to be distinguished from augitic basalt.

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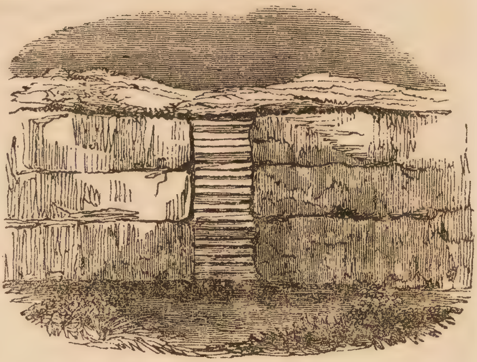

Basalt occurs both in horizontal tabular masses and in dikes, and both in dikes and masses exhibits the columnar, globular, vesicular, and amygdaloidal structure. When basaltic columns occur in tabular masses, they are usually vertical, as in fig. 55. In dikes they are smaller, and arranged horizontally, as in fig. 56, and are generally termed prisms. The globular structure is often visible in the decomposition of basaltic and volcanic rocks, and in a solid rock, called the orbicular granite of Corsica, in which balls or spheroids are disseminated through the rock, and consist of concentric alternating layers of hornblende and compact felspar.

From some experiments of Mr. G. Watt, it appears that the columnar structure of basalt arises from the pressure of numerous spheroids on each other during the process of cooling. He fused seven hundred weight of fine-grained amorphous basalt, maintaining the fire for six hours, and allowing it to cool so slowly that eight days elapsed before it was removed from the furnace. The mass was then four feet and a half long, two feet and a half wide, eighteen inches thick at one end, and four at the other; an irregularity of form highly favourable to the exhibition of the different kinds of structure arising from different rates of cooling. Where the mass was thin it was vitreous; where owing to the thichness, the cooling had been more gradual, it was stony, and there were parts exhibiting a transition from one state to the other. Numerous spheroids, sometimes two inches in diameter, had been formed, radiated with distinct fibres, and constituting concentric coats, where circumstances had favoured such an arrangement. In other parts, where the temperature had been sufficiently kept up, the centres of the spheroids became compact before they

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attained the diameter of half an inch. When two of these spheroids came in contact, they did not penetrate each other, but were mutually compressed (fig. 57), and separated by a well-defined plane invested with a rusty coating. Where several met they formed prisms.

Some basalts are vesicular, and contain small hollows caused by bubbles of gas or vapour, while the rock was in a fused state. These cavities have often been filled by infiltration with nodules of carbonate of lime, agates, zeolite, and other minerals. As these nodules have, in general, an elongated shape, resembling an almond, such basalts have received the name of amygdaloidal. Basalt possesses this vesicular and amygdaloidal structure, as well as the columnar, in common with lava. When, as is frequently the case, several alternations are observed in the same tabular mass of basalt, these appearances would seem to indicate that it was not produced by one, but by several ejections of fused matter, which assumed different characters, according to the different circumstances under which they burst forth. Basaltic rocks are of a very general distribution, being found in the neighbourhood of most active or extinct volcanos, as well as in situations where it would appear that there had been no volcanic cone or crater, but that the melted matter had forced its way through fissures beneath the bed of the ocean, and had thus flowed over other rocks. The largest known area occupied by basalt, is in the Deccan, as described by Colonel Sykes, where it covers many thousand square miles of surface. The chief British localities for basalt, are the north of Ireland, where it occupies a large portion of the county of Antrim; in Scotland, near Edinburgh, and in some of the Hebrides: in England, near Teesdale, in Yorkshire, in the counties of Northumberland and Durham, and in the Clee Hills in Shropshire. The great Cleveland dike, which ranges through parts of the counties of York and Durham, may be traced for nearly seventy miles. The finest instances of the columnar structure in basalt, occur in Fingal's Cave, in Staffa, one of the Hebrides, and at the Giant's Causeway, and at Fair Head, in the county of Antrim.

PORPHYRY.

The name is derived from a Greek word, signifying purple,—the porphyry used by the ancients for ornamental purposes being of that colour. The term is now applied to any rock having a compact base, in which distinct crystals are imbedded. The base is generally compact felspar, or its allied rocks, clinkstone and claystone. The imbedded crystals are either quartz or felspar, most commonly the latter, and these felspathic crystals are sometimes common, sometimes vitreous felspar. Porphyry has become so vague a term, as to convey no idea of the composition of a rock to which it is applied, unless associated with the name of the base. Thus we have claystone porphyry, clinkstone porphyry, felspar porphyry, and pitchstone porphyry. Each of these bases occur under various modifications of colour; and the diversity of aspects thereby occasioned, is still further increased by the various colours of the imbedded crystals, their different sizes and modes of aggregation, among which the crossing of the crystals is the most worthy of notice. These porphyries pass into simple rocks, by the gradual diminution of the number of their imbedded crystals; and since both the simple and compound rocks are frequently found in the same mass, hand specimens do not always represent the nature of the rock. The bases of these varieties of porphyry have been described under the simple minerals bearing the name of claystone, compact felspar, and clinkstone in the last chapter.

Felspar porphyry is by far the most common; it occurs both in overlying and interposed masses, sometimes having a columnar structure, and also in dikes traversing the strata. The British localities are North Wales, Glencoe, Ben Nevis, Ben Cruachan, and other parts of the Highlands of Scotland, the Island of Arran, Cumberland, Cornwall, and various parts of Ireland.

Pitchstone is a glassy felspathic rock having a great resemblance to pitch; it occurs in interposed beds and dikes traversing granite, secondary sandstone, and traps. It has sometimes a prismatic structure, sometimes occurs in curved lamellar concretions. Its structure is frequently porphyritic. The imbedded crystals are sometimes rounded, and converted into a gray or white enamel on the exterior, the smaller crystals being replaced by spheroidal grains, consisting entirely of the same enamel. This variety passes into pearlstone. Pitchstone likewise graduates into calcedony and chert, and into obsidian, a decided volcanic product. Dr. M'Culloch has observed a transition from basalt into pitchstone, on the outside of dikes of basalt, and also when they ramify into slender threads; and similar transitions from lava to pitchstone in the walls of dikes of lava on Somma, have been noticed by M. Necker and Mr. Lyell; a circumstance which is easily accounted for, from the more rapid cooling which would take place in such situations, than in the interior of the mass, and which the experiment of Mr. Watt, before alluded to, showed to be favourable to the production of the vitreous state. The British localities for pitchstone, are the Isle of Arran, and the Scuir of Egg.

VOLCANIC ROCKS.

We have already, under the head of basalt, alluded to the principal difference between the trap rocks and the products of active volcanos, as consisting in a greater degree of compactness in the traps, and in the prevalence of augite instead of hornblende in the lavas. The variety of simple minerals contained in lavas is very great. The vicinity of Vesuvius alone has furnished upwards of a hundred; two only, however, are in general present in sufficient abundance to be deemed constituents of the rock,—felspar and augite. Hence the usual division of lavas into trachytic and augitic or basaltic. Trachyte is composed chiefly of glassy felspar, with crystals of the same mineral. The name is derived from its peculiar *rough* feel (τραχυς). Quartz and mica, so common in the older igneous rocks, are comparatively rare in lava. Mr. Scrope has added a third division, to which, from its colour, he has given the name of graystone, intermediate in character between the trachytic and augitic lavas; but volcanic products are of such a compound nature, that it is extremely difficult to assign them names. The following is Mr. Scrope's arrangement:—

TRACHYTIC LAVAS.

Simple Trachyte. Compact felspar, with crystals of vitreous felspar.

Compound Trachyte, with mica, hornblende, or augite, and grains of titaniferous iron.

Quartziferous Trachyte, with crystals of quartz.

Siliceous Trachyte. When siliceous earth appears to enter largely into its composition.

GRAYSTONE LAVAS.

Common Graystone. Felspar, augite, hornblende, and iron.
Leucitic Graystone. Leucite supplies the place of felspar.
Melilitic Graystone. Melilite replaces the felspar.

AUGITIC, OR BASALTIC LAVAS.

Common Basalt. Composed of felspar, augite, and iron.
Leucitic Basalt. Leucite replaces the felspar.
Olivine Basalt. Olivine replaces the felspar.
Haüyine Basalt. Haüyine replaces the felspar.
Ferruginous Basalt. Iron is the predominant ingredient.
Augitic Basalt. The rock almost wholly composed of augite.

Many subaerial volcanos have ejected trachyte and basaltic lava, but most of the basaltic rocks have been formed under the pressure of the sea, or other strata, and have been subsequently elevated to the surface. This is the reason of their being more compact than subaerial lavas.

The following may also be mentioned as volcanic products:—Obsidian, a vitreous lava, being the result, no doubt, of rapid cooling, having a black colour in mass, but translucent in thin fragments.

In defending the aqueous origin of the unstratified rocks, the Wernerians were driven to deny, that this rock had ever been in a state of fusion; which was as rational as it would have been to have contended that bottle-glass had been formed as a chemical deposit from a state of aqueous solution.

Pumice is a light spongy lava, of a white colour, produced, most probably, by the access of gases or steam, to lava, in a state of fusion. It may be considered as the froth of lava. Transitions are observable in the same mass, from obsidian into pumice.

Volcanos also eject from their craters, besides currents of lava, vast quantities of dust, ashes, and stones, which being blown vertically into the air by the explosive force of gases and vapours, and falling round the sides of the vent, produce conical hills of a loose material. Similar materials, swept down by the torrents caused by heavy rains, and the melting of the snows, which frequently accompany these eruptions, give rise to streams of volcanic mud, or, as they are called, aqueous lavas, which, as they consolidate, form rocks of an earthy appearance, known by the name of volcanic tuff or tufa. Similar tuffs are produced when these light ashes and scoriæ fall into lakes and hollows. *Volcanic grits*, or sandstones, are distinguished by the angularity of the particles from sandstones composed of abraded materials. When the fragments are coarse, they are called *breccias:* when the fragments have been rounded by watery agitation, they are *tufaceous* conglomerates. These tufaceous rocks often inclose shells, and are sufficiently consolidated to receive a fine polish. The term *peperino* is restricted by the Italians to basaltic tuffs. The same kind of ejections of fragmentary matter must take place from the craters of submarine volcanos, though the conditions under which they occur, do not permit us to observe them.

The Island of Sciacca, or Graham's Island, which recently arose, and disappeared in the Mediterranean, consisted principally of loose scoriæ, which being dispersed by the waves, and agitated in the sea, would be spread over its bed, and form volcanic tuff, or sandstone, containing, most probably, organic remains.

In taking a general review of the unstratified rocks, we cannot fail to remark such a striking similarity among them, in composition, structure, and mode of association with other rocks, as to induce us to regard them as members of one family; as parts of a great mass of melted matter poured out, at different times, from the interior of the earth, and differently modified, according to the circumstances under which the ejections took place. Hornblende, or augite, and felspar, either compact, crystallized, common, or vitreous, enter into the composition of them all. They possess a crystalline texture, and affect, for the most part, a columnar structure. They all occur as intrusive beds, veins, or dikes, or as overlying masses, the connexion of which with a dike may often be clearly traced. We know that the different members of the group pass into each other, by insensible gradations; so that two or more of them may be found in the same dike, or mass, and that they graduate, in like manner, into undoubted volcanic products. We also know, by experiment, that when melted, the resumption of the stony character takes place, under circumstances favourable to gradual refrigeration, and that some of their constituent minerals have been formed artificially, in the crucible of the chemist.

If we examine the difference between the various members of the group, it becomes apparent that, taking the granitic rocks as a whole, they are distinguished by the prevalence of quartz, in crystals or concretions, and by the abundance of mica; and that in the trappean or basaltic rocks, mica diminishes in quantity, while hornblende considerably increases, and augite and vitreous felspar prevail in the modern lavas. The greater prevalence of the basaltic rocks over the granitic among the more modern formations, is also to be noticed. The difference between lava and basalt is such as might be expected between subaerial and submarine ejectments. What the peculiar modifying circumstances were which caused the formation of the granitic rocks so extensively during the earlier epochs of the world, we know not; extreme slowness of cooling, and very great pressure, not only from a deep ocean, but from superincumbent strata, may have been among these causes; but, whatever they were, it would seem, from the rocks of different ages which have been penetrated by the granite, that those circumstances have recurred at intervals, though far more rarely, during the more modern epochs, when those conditions prevailed which were favourable to the production of the basaltic rocks.

In the Wernerian system, granite and the other unstratified rocks were treated as aqueous productions; volcanos, which in modern times add so largely to the rocky mass of the earth's surface, were considered phenomena of recent date, quite unknown in the primæval ages of the world. The reason of this was, that Werner, who, in 1775, was appointed Professor of Mineralogy, in the Mining School of Freyberg, in Saxony, had studied geology, or, as he called it, geognosy, in a country far removed from any active volcano, and he had not extended his observations beyond his own immediate neighbourhood. He had great merit in directing the attention of his pupils to the natural position of minerals in certain rocks, and to the constant relations of superposition that prevail among them; and a great impetus was given to the study of geology by the charms of his eloquence and his manners, and the enthusiasm which they excited in his hearers; but his system contained this radical defect, that his generalizations were founded on too limited an induction.

> Urbem quam dicant Romam Melibœe putavi
> Stultus ego huic nostræ similem,

is a confession which might often be made by philosophers as well as peasants, if they had equal shrewdness with Tityrus in disçerning their errors, and equal candour in acknowledging them; and by none could it have been uttered with more propriety than by Werner. He had framed a theory of the earth, which was made to accommodate itself, in its minutest details, to the phenomena observable in his own valley, and to no others; and such was the veneration in which he was held by his followers, that to doubt of the existence of one of his universal formations, even the most problematical, was looked upon as a pestilent philosophical heresy; and there were many of his disciples who spent their lives in interrogating nature only to misinterpret her language, and to torture it into accordance with the dogmas of their oracle, and with the nomenclature and classification of his "geognosy."

STRATIFIED ROCKS.

Origin of the divisions Primary, Transition, Secondary, and Tertiary.

We proceed now to the consideration of the stratified rocks. These form a series, the total depth of which has been estimated at nine miles. About one-fourth of this may be assigned to the lower part of it, which is destitute of organic remains; some of its members, which taken as a mass, are the lowest, being intimately connected in composition with some of the unstratified rocks to which, on the evidence already adduced, an igneous origin, has been attributed. To the non-fossiliferous strata, no classification can be applied that is not based on their mineral characters. The remainder of the stratified series can only be regarded mineralogically as a succession of clays, sandstones, and limestones, alternating in no fixed order, as far as regards their mineral composition, and changing that composition in the same horizontal plane, but capable of being divided into groups, characterized over very extensive areas by peculiar assemblages of organic remains. The classification of them must, therefore, be founded on their zoological characters.

The first attempt at a methodical arrangement of rocks was made by Lehman in 1759, who divided them into *primitive* and *secondary*. The primitive were those which contained no organic remains, or fragments of other rocks, and which he supposed were formed with the world, and before the creation of animals.

The secondary were the fossiliferous strata which he supposed to have resulted from the partial destruction of the primitive rocks by a general revolution. Out of these, Werner formed a third class, which he named *transition*, from having observed that between the primary rocks and those in which the characters of the secondary class were most strikingly developed, there existed an intermediate group, containing few organic remains, and approaching the crystalline character of the primary rather than the fragmentary character of the secondary rocks.

To the remainder of the secondary strata, out of which this class was taken, he gave the name of *Floetz*, or horizontal, from an erroneus belief, founded on the observation of a limited district, that rocks of this class were stratified only in horizontal planes, which is true only of low-lying regions; for on the flanks of the Alps and the Pyrenees the horizontal rocks of Werner are found as highly inclined as any of the primitive. His floetz rocks terminated in the ascending order with the chalk, and as the investigations of Cuvier and Brongniart brought to light some strata above the chalk, important on account of their zoological relations, which were so different from those of the secondary class, the followers of Werner were compelled to subdivide their floetz rocks into older and newer floetz, comprising under the latter name those formations which, by other writers, were called Tertiary.

Mr. Conybeare proposed, in the year 1822, an entirely new nomenclature for these general divisions, without reference to hypothesis, and founded entirely on their undoubted relative position. Taking the carboniferous series,—a group well defined by mineral characters all over Europe at least,—as his point of departure, and including in it the mountain limestone, to which he gave the name of the carboniferous, he called this group the medial order, from its position near the middle of the series. The transition and primitive rocks of Werner he called the *inferior order*. The *supermedial order* extended from the coal measures to the chalk, which it included; and under the name of the *superior order*, he classed all the regular tertiary strata then known.

There, is, however, so much inconvenience in changing established scientific names, and the disadvantages so nearly counterbalance the advantages, unless the change be made with the concurrence of the cultivators of science in all countries, that there is always a repugnance to innovation in matters of this kind; and in other sciences, besides geology, objectionable names are retained in current use in preference to others that would be more appropriate. The system of Mr. Conybeare, therefore, never established itself as a part of geological nomenclature. The only change he succeeded in introducing was the substitution of the name of carboniferous limestone for that of *mountain*, or *transition*, or *encrinitic* limestone, which it had previously borne.

No better success attended an attempt made about the year 1830 by Mr. De la Beche, to abolish the term Primary, Transition, Secondary, and Tertiary, and to divide the rocks constituting the earth's crust into the two natural sections of STRATIFIED and UNSTRATIFIED, subdividing the fossiliferous series into the nine following groups, in the descending order: 1. The *Modern* or *Formations now in Progress.* 2. The *Erratic Block Group*, a provisional group, containing transported boulders and blocks, and gravels on hills and plains, apparently produced by greater forces than those now in action. 3. The *Supracretaceous Group*, the tertiary strata of other authors. 4. The *Cretaceous Group.* 5. The *Oolitic Group.* 6. The *New Red Sandstone Group.* 7. The *Carboniferous Group.* 8. The *Grauwacke Group*, or upper part of the transition class of Werner, since named by Mr. Murchison the *Silurian System.* 9. The *Lowest Fossiliferous Group*, answering to the lower part of the transition class, since named by Professor Sedgwick the *Cambrian System.*

The classification and nomenclature of Werner, however, with some modifications, continued in use, partly on account of their convenience, and from that repugnance to change to which we have before alluded; and partly from a feeling that we were not yet in possession of sufficient data to be able to frame a systematic nomenclature of the stratified rocks. Since, then, any new classification could be considered only as provisional, it seemed a matter of comparative indifference which of two imperfect systems was adopted. Geologists, therefore, continued to speak of primary, transition, and secondary rocks, merely as a convenient mode of designating certain groups of strata, without supposing that these divisions had any foundation in nature, and without reference to the sense in which those names were originally imposed.

It had, however, long been evident that the name of Transition must be abandoned, on account of the indefinite manner in which it had been applied, some geologists limiting it to those older rocks which were supposed to contain the earliest traces of organic remains, others including in it the whole of the carboniferous series. The term Fossiliferous grauwacke, which it was proposed to substitute for it, was deemed by some geologists, liable to equal objections, because, having been originally applied to a rock of a certain mineral character, it must, if used in the proposed new sense, have comprehended a variety of rocks of very different composition, an ambiguity of expression which they considered likely to lead to much confusion.

The researches of Mr. Murchison among the rocks of the Welsh border, and of Professor Sedgwick among the slate rocks of Wales and Cumberland, not only placed in a still stronger light the necessity of some new and precise mode of designating the rocks below the old red sandstone, but furnished us with the means of dividing them into several important groups, and thus reducing into something like order, a great assemblage of beds, which, occurring abundantly in England, Scotland, Ireland, Germany, Prussia, Sweden, and North America, were, till recently, involved in the greatest obscurity and confusion.

From the upper part of the series, below the old red sandstone, Mr. Murchison has separated a system of rocks, which, in the counties bordering on Wales, is so largely developed as to comprise a total thickness of 7500 feet, divisible into formations by separate and peculiar groups of organic remains. To this system he gave the name of the Silurian, from the Silures, one of the principal tribes of the ancient Britons, who inhabited the district in which this system of rocks was first observed and is most extensively developed. These rocks he has further subdivided into the upper and lower Silurian, each subdivision comprehending two formations. These rest, in some cases conformably, in others unconformably, on another great system, in which traces of organic remains occur, and which are distinguished in Wales and Cumberland by a subcrystalline and concretionary structure, and by having a slaty cleavage, that is, being capable of indefinite subdivision in planes transverse to those of the stratification. This system, Professor Sedgwick, whose researches are as yet only partially published, has named the *Cambrian,* from the country in which it occurs extensively developed, in juxtaposition and conterminous with the Silurian, which it succeeds in the descending order; and he has subdivided it into the upper and lower Cambrian.

Abandoning, then, the terms Transition and Grauwacke series, we shall divide the stratified rocks into primary, lower secondary, upper secondary, tertiary, and modern. The primary will be limited to the non-fossiliferous strata. The lower secondary will commence with the oldest formation in which organic remains are found, that is, at present, the lower Cambrian of Professor Sedgwick, and will include, in the ascending order, the carboniferous system. The upper secondary will commence with the new red sandstone, saliferous, or poikilitic system, and will terminate with the chalk. The tertiary will comprise all those regular deposits above the chalk in which existing species begin to appear, mixed with others that are extinct, and which Mr. Lyell has divided, according to the proportion of shells of existing species contained in them, into the eocene, miocene, and older and newer pliocene strata. The term *Modern* will be confined to those formations which contain human remains, or those of existing species of animals unmixed with others that are extinct.

With respect to that portion of the loose covering of the earth, to which we have before alluded, and which Mr. De la Beche refers to an erratic block period, the marine remains found in it, within the British Islands at various heights, and in numerous localities, have hitherto all been of existing species, and on that evidence it should be classed with the modern formations. Most of the remains of mammalia contained in it belong to extinct species, or to species no longer inhabiting Europe. But while we believe in the existence of a period intermediate between the close of the tertiary era and the commencement of the present order of things, characterized by the passage of a large body or bodies of water from north to south over a great part of the northern hemisphere, there are others who consider these phenomena as the effects of causes now in action, and acting with the same intensity as at present. According to them, this transport took place before a large portion of England had emerged from the sea, and the blocks were floated upon ice. Our reasons for dissenting from this hypothesis will be stated in a subsequent chapter.

PRIMARY, OR NON-FOSSILIFEROUS STRATIFIED ROCKS.

The primary strata are gneiss, mica schist, hornblende schist, chlorite schist, talcose schist, quartz rock, primary limestone, and argillaceous schist.

Gneiss.

Gneiss may be called slaty granite. It is composed of the same ingredients as that rock, viz., quartz, felspar, mica, and hornblende, united in various proportions, with the occasional absence of one or other of them, and the presence of a few other minerals. The distinctive character of gneiss consists in some of its component minerals, generally the mica and hornblende, being arranged in layers parallel to the stratification, so as to impart to the rock a foliated or laminated appearance, or to give it a schistose character, sometimes so perfect as to admit of its being cleaved for economical purposes. This character becomes less perfect when the gneiss is in contact with granite, or traversed by veins of it, and, at the point of contact, disappears entirely, so that the two rocks cannot at their junction, be distinguished from one another. Fine-grained gneiss passes by the disappearance of felspar into mica schist; by the prevalence of quartz into quartz rock, and of hornblende into hornblende schist. The stratification of gneiss is irregular and contorted, the dimensions of the strata variable. Where the rock occurs in large masses, they are thick; when they alternate frequently with others, they are thin. When they are not separated by such alternations, the distinction between the several beds is marked by a change in the proportions of the ingredients. Gneiss is, in many countries, the most abundant of the primary strata, occurring in large masses, which occupy extensive districts, and form lofty mountains, without any other alternating rock. In such cases it reposes upon granite, and is succeeded by the other primary strata, but in some instances succeeds one or other of these, the series alternating in large masses.

There are other instances in which a large series of strata, consisting principally of gneiss, contain alternating strata of other rocks in inferior proportions. The most common of these is hornblende schist; mica schist and quartz rock are next in abundance; argillaceous schist is more rare. Strata of gneiss are often invaded by veins of granite, which are not always transverse to the stratification, but sometimes run parallel with it, assuming for short spaces the stratified appearance of gneiss, and when of large dimensions, are liable, without very careful observation, to be mistaken for stratified granite.

The British localities for this rock are the Western Isles and northwest Highlands of Scotland.

MICA SCHIST.

MICA SCHIST is a confusedly crystalline compound of quartz and mica, united in different proportions. It has a foliated or laminar texture, and is more or less fissile according to the proportion and mode of disposition in which the mica enters into its composition. It is sometimes capable of being separated into coarse slates; sometimes the lamellar fracture is very irregular and imperfect. There are cases in which it approaches a granular texture; but when the quartz wears the most granular appearance, it is always united by a crystalline cement of that mineral.

Beds of mica schist are sometimes affected by large contortions, but there are many cases in which, when the contortions are minute and intricate, they seem only to involve the laminæ without extending to the bed itself. This contorted lamination so common in the rocks of this age, is a peculiarity of structure which seldom occurs in more recent strata, and is, by some geologists, supposed to have resulted from agitation of the waters of the ocean in which they were deposited, or of the soft sedimentary matter by heat; and they compare it to somewhat similar appearances in the sediment of steam boilers; others attribute it to lateral pressure on soft laminæ originally horizontal, and illustrate this view of its origin by placing layers of clay, or of cloth, of different colours, under a weight, and applying pressure to the sides.

The stratification of mica schist, when occurring, as is frequently the case, in large masses, occupying great tracts of country, is very difficult of detection. When the beds are not separated by alternating rocks, they are distinguishable, like those of gneiss, by changes in the proportions of their component parts.

By the admission of felspar it graduates into gneiss; and by the preponderance of the quartz, into quartz rock, with which it occurs extensively associated. The colour of the different varieties of mica schist depends upon the quantity of mica which they contain, which varies in hue from white to black, the quartz being almost invariably colourless. The prevailing colour of the rock is therefore gray, except when passing into chlorite schist, when it becomes green.

Mica schist differs from gneiss in not being traversed so much by veins of granite. These only occur in it when in contact with the granite, the veins being small, extending only a short distance from the mass, and their origin being easily traced; but it is subject to be much penetrated by veins of quartz, both transverse and parallel to the laminæ of stratification, and when these are contorted, the veins are contorted also.

Mica schist, like gneiss, forms extensive tracts of country, and lofty mountains, but it also occurs in beds of a few feet in thickness, associated and alternating with gneiss and quartz rock.

The British localities are the Scotch Highlands and the northwest of Ireland.

Chlorite Schist.

The essential ingredients of this rock are chlorite and quartz, occasionally mixed with felspar and hornblende. It may be distinguished from mica schist by its green colour and saponaceous feel. Its most extensive association is with mica schist, into which it passes in so insensible a manner, by the gradual mixture of the two minerals with quartz, that it is often difficult to decide which name to assign to the rock. It is under such circumstances that it forms masses of the greatest extent. It likewise occurs largely associated with argillaceous schist, into which it passes, by a transition more or less perfect. It alternates, in smaller strata, with gneiss, and by the addition of felspar graduates into some of the chloritic varieties of that rock.

Chlorite schist, under a great variety of aspects, occupies, as we have before observed, a large portion of the Isle of Anglesey, and a small patch of it is found at the southwest extremity of Caernarvonshire.

Talcose Slate.

This rock is composed of talc alone or of talc and quartz. It resembles the two preceding rocks, but is distinguished from them by the peculiar characters of the talc, and by its colours, which are lead-gray, white, and obscure green. It occurs only in beds of very limited thickness and persistency, imbedded in gneiss, mica schist, and chlorite schist, and in a few rare instances in argillaceous schist, into all of which it gradually passes.

HORNBLENDE SCHIST.

Under this term, Dr. M'Culloch proposed to include all those compounds, previously known by the names of hornblende rock, primitive greenstone, and greenstone-slate, whether possessing a schistose structure or not, which are clearly contemporaneous with the strata among which they occur. Its ingredients are hornblende and felspar, but the hornblende sometimes prevails to the exclusion of all other minerals. It occurs alternating with gneiss. It is rarely met with in large masses so as to form extensive tracts, without the alternation of other rocks. It is most frequently associated with gneiss, and less commonly with mica schist. When associated with argillaceous schist, it is occasionally observed to pass insensibly into that rock.

QUARTZ ROCK.

This is a stratified rock, the beds of which vary in dimensions, the distinctions between them being more strongly marked than those of gneiss and mica schist, with which it is often associated. It is divided by natural joints, which cause it to break into rhomboidal or rectangular fragments. The variations in its mineral character are numerous; its most simple form is thus described by Dr. M'Culloch:—" It is occasionally, but rarely found in a compact state, and crystalline throughout, little differing from quartz, as it occurs in veins, but even in those cases showing a constant tendency to divide in parallel beds. More frequently, when pure, it has an aspect obscurely granular, which by degrees becomes somewhat lax and arenaceous, the grains varying in size, and in the intimacy of their union. In some of these examples, it appears to be a granular crystalline mass; in others it possesses a mixed mechanical texture; while in a third, the rounded aspect of the grains, and the small number of points of contact, appear to indicate an origin chiefly mechanical, and resulting from the agglutination of sand. Cavities are sometimes found in the specimens containing regular, though minute crystals of quartz."*

There are other varieties, consisting of quartz intermixed with felspar, and quartz intermixed with mica, forming the passage into gneiss and mica schist, with both of which rocks it alternates, as also with argillaceous schist. The colour of quartz rock, when pure, is white, but it occurs of other shades, as ochre-yellow, and red. The presence of mica often produces a gray-coloured rock, and a mixture of felspar communicates a flesh-red tint to this compound form of quartz rock.

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* M'Culloch's Classification of Rocks, p. 323.

Argillaceous Schist.

This is a schistose rock, consisting chiefly of indurated clay, varying in hardness, fissility, and composition, and undistinguishable, except by position, from the argillaceous slates of the lower secondary series. Its essential minerals are the indurated clay which forms the whole of the simple varieties, and quartz and mica, which enter into the compound varieties. The prevalent colours of the finer kinds are lead-blue, sometimes red and purple, gray and yellow. The green varieties contain chlorite, and pass into chlorite schist.

Crystalline, or Primary Limestone.

A remarkable peculiarity attending the primary strata consists in the very small proportion which the calcareous rocks bear to the rest of the group, thus affording a striking contrast to the secondary rocks, among which carbonate of lime is so largely developed.

Primary limestone is a simple rock, varying from a highly crystalline texture, both large and fine-grained, to compact. It is of various colours, but generally white. The purest and whitest varieties, sometimes called saccharine limestone, from their resemblance in small masses to sugar, are much prized as statuary marble.

This rock is generally met with in irregular beds, alternating indifferently with all the members of the primary series. When in contact with granite, it is often indurated, and when very impure, is sometimes converted into a cherty substance. When interstratified with gneiss or mica schist, it is apt to acquire so much mica as not to be easily distinguished from those rocks on a laminar fracture.

The members of the primary strata which occur in the greatest abundance, and in the largest masses, are gneiss and mica slate. The series may therefore be conveniently divided into the gneiss and mica schist systems. The former, which is the lowest, consist of strata of gneiss, mica schist, hornblende schist, quartz rock, primary limestone, and argillaceous schist, alternating in no certain order. In the mica schist system, the most quartzose and felspathic portions are found towards the bottom of the system, the most argillaceous portions towards the upper part. The limestone occurs imbedded in the mica schist.

Geographical Distribution.

The primary strata occupy a large portion of the surface of the earth. There is scarcely a country in any part of the world in which they are not exposed to view, either by the original absence of secondary series, or by their denudation or disruption.

The range of these strata in the British Islands, is principally confined to the northwest Highlands of Scotland and Ireland. The Hebrides, from Lewis to Mainland, together with Coll and Tyree, consists of gneiss, and the same rock occupies the greater portion of the Highlands north of a line drawn from the head of Loch Awe, to Aberdeen, penetrated irregularly by the granites of Argyleshire, the Grampians, Peterhead, and Aberdeen.

Mica schist, associated with quartz rock, and crystalline limestone, covers the western parts of the counties of Galway, and Mayo, in Ireland, reappears on the north side of Donegal Bay, and expands over the counties of Donegal and Derry, and the northwest of Tyrone. It crosses the Channel to Isla, Jura, Colonsay, and Cantyre, dividing on the coast of Argyleshire into two branches, one of which skirts the eastern shore of Loch Linnhe, and extends up the valley of the Caledonian Canal to Fort Augustus; the other, by far the largest, occupies the space between the head of Loch Awe, and the mouth of Loch Long, bordering the Grampians on the southeast, by Killicrankie and Dunkeld, and terminating in a narrow band, which ranges through Angus and Mearns to Stonehaven. A smaller tract extends from the base of Cairn Gorm to Cullen. The upper part of the mica schist about Loch Lomond and Loch Earn becomes chloritic, and the rocks of this system appear under the same form in Anglesey, where they occur in three parallel bands, ranging across the northwest centre, and southeast of the island. The strike is E.N.E. and W.S.W., and the same rocks reappear in Caernarvonshire, extending along the coast from Porthdynlleyn to Bardsey Island. They are covered by the clay-slate system, and in parts of Anglesey, by the old red sandstone and carboniferous limestone.

Very slight traces of gneiss are found in Skiddaw, between the granite and the rocks of the clay-slate system, and a narrow band of that rock, with mica or chlorite schist, skirts the granite of Wicklow.

The principal masses of quartz rock in Scotland, occur in a line bordering on the N.W. of the mica schist districts of Argyle, Perthshire, and Banffshire. Quartz rock likewise skirts the N.W. coast from Loch Eribol, to the southern part of Skye, and occupies large breadths in Isla and Jura. Mountains of quartz rock are remarkable for their conical peaks, as Schiehallion, the Paps of Jura, and the Greater and Lesser Sugar-loaf, in Wicklow.

Granite is rarely in contact with these strata in the British Isles, without sending off veins into them. The other igneous rocks which have pierced through them are porphyry, as an overlying mass, constituting the summit of Ben Nevis, and as dikes in Ben Cruachan and Glen Coe. Dikes of greenstone and trap are by no means uncommon. Serpentine occurs at Portsoy, in Iona, Anglesey, and Connemara.

Gneiss and mica slate are found in France; they occupy extensive tracts in Norway, Sweden, and the north of Russia; they constitute the central lines of the Alps and other mountain ranges on the continent of Europe, having been brought up from beneath the overlying strata by the subterranean forces which upheaved those chains. They occur extensively in the Brazils, in the United States, and the remotest parts of America which have yet been visited. We know little of the geology of Africa, but they have been found there also. They constitute a large portion of the island of Ceylon; they enter extensively into the composition of the Himalaya Mountains, and are by no means rare in other parts of the continent of Asia. They are, indeed, so extensively distributed, and wherever found, appear under such a general similarity of character, that we are justified in assuming that they exist beneath the secondary strata in all parts of the world, and that they have been produced by some general causes acting during the period of their deposition over the whole globe.

Controversy as to their Origin.

The nature of those causes has afforded matter for as much controversy, as the origin of the unstratified rocks. Werner maintained that they were formed with the world, and were a chemical deposit from "a chaotic fluid," which held their constituents and those of granite in a state of chemical solution. As the waters of this ocean gradually precipitated the minerals with which they were charged, they became capable of supporting animal life, chemical deposits ceased, crystalline rocks were no longer formed, and the secondary strata were deposited, exhibiting entirely a fragmentary structure, and containing the imbedded exuviæ of animals.

Hutton, a Scotch philosopher, contemporary with Werner, propounded a very different doctrine respecting the origin of the unstratified rocks and the primary strata, which has triumphed over the rival hypothesis, and has been confirmed in some of its most important points, by the observations of the geologists who succeeded him. He taught that no geological phenomena afford evidence of the beginning of things; that the oldest rocks we behold are derivative, the ruins of pre-existing rocks destroyed by the slow erosion of atmospheric agency, and that their detritus, borne by rivers to the ocean, and loosely deposited over its bed, became afterwards consolidated by heat, and then upheaved and fractured. The crystalline, or primary strata, according to him, were originally mechanical deposits similar to the secondary rocks, but altered by the long-continued action of heat; while granite had crystallized from a state of fusion, and had slowly cooled under great pressure. In support of those views, he and his friends, Playfair and Sir James Hall, collected much of that evidence which we have already adduced as proofs of the igneous origin of the unstratified rocks; and he was himself the first observer of veins ramifying from granite into the superincumbent strata.

The establishment of the igneous origin of granite has cleared the ground of many difficulties, and that part of the Huttonian theory which relates to the primary strata appears to be rapidly gaining ground among geologists.

The secondary and tertiary rocks present unequivocal proofs of a mechanical and aqueous origin. In their arrangement in horizontal beds, in the subdivision of these beds into thin layers, indicating successive deposits, and in the shells which they contain, we have exact counterparts of those beds of sand and silt now forming under our eyes, at the mouths of rivers, and in ponds and lakes; and some of the tertiary strata are not more consolidated than these modern formations. The primary strata possess the same character of division into thick beds, and of subdivision into laminæ; but they contain no organic remains, and they possess a crystalline structure, or, if in any of them we detect obscure traces of a fragmentary origin, those fragments are united by a crystalline cement. The crystalline state of a rock is no proof, either of an igneous or an aqueous origin, for crystallization may take place from a state of fluidity produced either by fusion or solution.

We see crystalline beds of limestone that contain organic remains, and are of aqueous origin; we also know that carbonate of lime is daily dissolved, and re-deposited by water, and that siliceous earth is held in solution by the waters of thermal springs. Clay-slate, one of the primary strata, never could have resulted from a state of fusion, for it is but clay in different states of induration, and is thus clearly connected with an aqueous deposit. It likewise passes by such insensible gradations into chlorite schist, mica schist, and quartz rock, and these again into gneiss, that it becomes sometimes difficult to define the limits between these several rocks; and it is impossible to assign a different origin to substances so closely related. On the other hand, gneiss passes into granite, which we consider proved to be of igneous origin. The Huttonian hypothesis, therefore, which considers the primary strata as an altered condition of sedimentary deposits, appears to offer the only solution to the difficulty.

Whether our planet has ever been in a state of general fusion, and whether it consists, even now, of a mere crust, resting on an incandescent nucleus, as some have supposed, reasoning from the phenomena of volcanos, and from the increase of temperature in deep mines, we know not; but we are certain that there are masses of melted matter connected with volcanos, deeply seated below the granite; and large masses of incandescent matter, accompanied by intensely heated gases, may have produced in sedimentary strata changes of texture of every degree between the slightest induration and crystallization. The experiments of Sir James Hall, before alluded to, proved that heat under pressure, was capable of forming crystalline rocks out of their fragments reduced to powder; and when a specimen of crystalline marble, which he had formed, by this process, out of pounded oyster-shells, was shown to a sculptor, he remarked, without knowing its history, that wherever such marble might be found, a quarry of it would be highly valuable. In studying in the laboratory of Nature the phenomena observable when the unstratified rocks have intruded among the sedimentary, we see exhibited, in a more striking manner, and upon a larger scale, the effect of heat upon these deposits. We not only see earthy limestone converted into crystalline marble, but we meet among the altered rocks with counterparts of all the primary strata. We see beds of shale converted into jasper and flinty slate, and beds of sandstone into quartz rock, under such circumstances that we can trace the gradual passage from the unaltered into the altered rock. There are also instances in which, when the earlier clay-slates have been traversed by dikes or veins of granite, or the basaltic rocks, the slate, near its contact with the veins, is sometimes converted into horneblende schist; in other cases it becomes micaceous, acquiring the character of mica schist or gneiss; and in others again, is converted into a hard-zoned rock, strongly impregnated with felspar. In many of these cases, alteration of texture, and re-arrangement of the component particles, appear to have taken place without actual fusion.

Though it is now very generally admitted that these rocks have undergone alteration from heat, there is a difference of opinion as to the extent of that alteration, and the time when it took place. Those who consider that the absence of organic remains is original, and who regard granite as formed by the cooling of the globe from a state of general fusion, suppose that the primary strata resulted from the rapid decomposition of this granitic crust when aqueous action commenced, and that the high degree of temperature still remaining in the earth only effected their consolidation as they were formed, and impressed upon them that peculiar kind of lamination which has been before noticed. In support of these views they appeal to the fragmentary and abraded character of the felspar and mica in gneiss, which they state to be destitute of the external crystallization seen in granite.

The advocates of the other hypothesis, who suppose that the crust of the earth nowhere exhibits the commencement of aqueous action and organic life, contend that there was no original difference between these strata and ordinary argillaceous and arenaceous deposits; but that as aqueous action adds to the mass of strata above, those previously deposited are melted down into granite below, and in their passage into that rock assume the characters of mica schist and gneiss, accompanied by obliteration of organic remains. In support of this hypothesis, they adduce the undoubted fact of the fluidity of granite at various epochs, and the partial changes produced in the more recent sedimentary deposits near their contact with igneous rocks.

The Fossiliferous Strata.

Having now described the unstratified rocks, and the non-fossiliferous strata, and having briefly adverted to the evidence in favour of the igneous origin of the former, and the metamorphic, or changed, condition of the latter, we shall proceed to the classification of the fossiliferous strata. In attempting to divide them into groups, distinguished by mineral composition, we should soon discover that we were engaged in a hopeless undertaking. It is true, we might find some general mineral characters, distinguishing the principal masses over limited regions; but these distinctions would fail us, when we should attempt to extend our generalizations to other districts at the distance of only two or three hundred miles. And again, when we should begin to frame a mineralogical classification of the subordinate members of any one of these principal masses, locally distinguished by some peculiar mineral character, such as that of producing coal, or rock-salt, or lead, we should soon be bewildered among the long and varying succession of shales, limestones, and sandstones, with which every fresh section would overwhelm us.

William Smith discovers that Strata may be identified by their Organic Remains.

In the organic remains, however, of the secondary strata, we have a clue to guide us out of this labyrinth, and a means of identifying the different formations in very distant localities. The merit of this discovery is due to William Smith, a land-surveyor of Oxfordshire, the "Father of English Geology." He was born at Churchill in that county, a place abounding in fossils, "the play-things of his childhood, and the objects of collection in his early youth." This, says Professor Sedgwick, "is one of many instances where things, in themselves inconsiderable, act powerfully on peculiar minds, so as to influence the whole tenour of after life. During his boyhood, his habits of observation became confirmed by lessons in practical surveying; he remarked the alternations of argillaceous and stony strata, and thence became acquainted with the origin of springs, and the true principles of draining." During the course of his employment as a land-surveyor, he had extensive opportunities of examining the outcrop of the principal secondary strata of central and southern England, and formed collections of their organic remains, which his first care on becoming a housekeeper, in 1795, and having apartments of his own, was to arrange stratigraphically.

He ascertained that certain groups of fossils were peculiar to certain strata, and that by organic remains alone, the true order of succession might be determined, when the beds themselves were obscure. He subsequently extended his observations to the north of England, tracing the strata along their basset edges, and ascertaining their order of succession, and general dip towards the east. He conceived the idea of representing on maps the area occupied by their outcrop, and, finally, completed a geological map of England, which was published in 1815. All this he performed alone, unaided, unpatronised, thus accomplishing for England, as was remarked by Daubisson, in twenty years, what many celebrated mineralogists had only effected for Germany in half a century.

The prospectus which he published, in 1801, of a work entitled *Accurate Delineations and Descriptions of the Natural Order of the various Strata that are found in different parts of England and Wales, with Practical Observations thereon*, met with no encouragement. "Why," says Professor Sedgwick, "his hopes of patronage were disappointed, and why his works were so long retarded, not by any want of zeal on his part, but by want of assistance from the public, it is not for me now to inquire. The fact, however, is not difficult of explanation. At the time his prospectus made its first appearance, none of the magnificent discoveries of Cuvier and Brongniart, were, I believe, published. The Geological Society had no existence; the branches of natural history connected with secondary geology were little cultivated, and indeed, almost unknown in this country; and hence some persons, perhaps, doubted the reality of Mr. Smith's pretensions, on a subject they had been taught to regard as empirical: and the public at large took little interest in what they did not comprehend. He suffered, therefore, as many men of genius have done before him, in his peace, and in his fortune, from what, in our estimation, constitutes his chief honour,—from outstripping the men of his own time in the progress of discovery."*

The generalization that strata are to be identified by means of the fossils contained in them was soon pushed beyond its proper bounds, and it was supposed that the presence or absence of a particular species, or genus, was sufficient to establish an identity between the rocks of the most distant regions. Such distinctions proved as little to be relied on, except within very limited districts, as mineral characters alone; and there is no doctrine enforced more strongly by those whose knowledge of organic remains is the greatest, and who have had the most extensive practical experience in the identification of strata, than this, that we can only safely rely on the succession of large groups of fossils.

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* Sedgwick's Address, on presenting Mr. Smith with the Wollaston Medal.—Proceedings of Geological Society, vol. i., p. 277.

The order of succession existing among the stratified rocks is principally founded on observations made within the limits of Europe. Great Britain affords examples of every system of strata at present recognised. In Scotland, as we have just seen, there is a large extent of gneiss and mica schist. With the exception of the poikilitic system, which is less developed with us than in France and Germany, England is classic ground to the student of secondary geology; and our carboniferous, oolitic, and cretaceous systems, so largely developed, and rendered so celebrated by the generalizations to which they conducted Smith, have long been the types of that part of the series. Wales and Siluria afford normal groups, worked out by Sedgwick and Murchison, with which they are now comparing their equivalent strata in other parts of Europe. The tertiary deposits are best studied on the Continent, where they occupy a large portion of the surface; but the south-east of our island affords characteristic specimens of the eocene and pliocene epochs.

The English Order of Succession applicable to the rest of Europe.

When we compare the series of stratified rocks in different regions, we find a certain general resemblance, accompanied by local differences. Equivalents of each of the systems, as exhibited in England, can be traced over the whole of the north of Europe. In France and Germany we are even able to identify some of their subdivisions; but when we cross the Alps, and still more when we extend our researches to more distant regions, we are scarcely justified, with our present information, in making a more detailed distribution of the rocks of extra-European countries, than into the leading divisions of primary, secondary, and tertiary.

The great divisions of Primary, Secondary, and Tertiary, are found in all Countries yet explored.

These are found in all countries yet explored, maintaining wherever they occur together the same relative position as in Europe, that is to say, we find at the surface deposits whose organic remains exhibit an approach to species inhabiting the neighbouring land and sea, while below them are rocks having a general resemblance to our cretaceous, oolitic, and carboniferous systems; the base of the whole being clay-slate (sometimes fossiliferous,) mica slate, and gneiss. It will require many years of observation to determine whether a more minute identification can be established.

The extra-European countries, in which the greatest progress has been made in the examination of the fossiliferous deposits, are North America and India, and these researches are now conducted with a more temperate spirit of generalization than that which till lately prevailed. Geologists have now learned that, in exploring distant regions, they have first to ascertain the series of deposits actually existing in a given country, and the divisions of which they are susceptible, before attempting to identify any of its members with European strata.

The Indian geologist is beset with many temptations to deviate into a less prudent course, from the close approximation which certain rocks in the Himalayas offer to the lias and oolites of the English type; from the presence of extinct pachyderms of the Paris basin, in the tertiaries of the Sewalik Hills; and from the recent discovery, in the district of Assam, of strata containing many marine molluscs, identical in species with those of the *calcaire grossier.*

CHAPTER XI.

Synopsis of the Stratified Rocks—imperfections of our present classification—the fossiliferous series forms one continuous group when not broken by local disturbances—indefinite limits of the transition group of different authors.—Lithological characters of the Cambrian system—jointed structure, and slaty cleavage—rarity of organic remains—absence of land plants—geographical distribution of rocks of this system—its types, as exhibited in Wales and Cumbria—subdivisions—similarity of the Cambrian and Silurian systems—igneous rocks, and metallic veins.—Silurian system—lithological characters—subdivisions—increase of organic remains—fishes—trilobites—rarity of plants—probable conditions under which the Silurian strata were formed—geographical distribution—associated igneous rocks—altered sedimentary strata.

FOSSILIFEROUS STRATA.

Older Secondary Rocks.—Cambrian and Silurian Systems.

Synonyms. Transition Series; Fossiliferous Grauwacke, and Grauwacke Slate; Primary Fossiliferous Strata, English authors. *Grauwacke schistoide*, French. *Grauwackenschiefer*, German. Grauwacke Limestone, Transition Limestone, English authors. *Calcaire de transition*, *Calcaire intermediaire*, French. *Uebergaugskalkstein*, German.

The following Table exhibits a synoptical view of the succession of stratified rocks, as found in Great Britain; their arrangements into the three classes of Primary, Secondary, and Tertiary; and their division into minor groups, termed systems and formations:—

MODERN GROUP—*Lacustrine, Fluviatile, and Marine Deposits, now in progress.*				
ERRATIC BLOCK GROUP—*Diluvium—Northern Drift.*				
STRATIFIED ROCKS.				
	Systems.	*Thickness.*	*Formations.*	*Subdivisions.*
		Feet.		
TERTIARY STRATA.	NEWER PLIOCENE.			Lacustrine and fluviatile deposits of Market Weighton, and the Vale of Thames.
	OLDER PLIOCENE.			Norwich crag.
	MIOCENE.	11 to 30		Red crag. Coralline crag.
	EOCENE.	600 to 1800		Bagshot sand. Fresh-water beds, Isle of Wight. London and plastic clay.

STRATIFIED ROCKS.—Continued.

	Systems.	*Thickness.* Feet.	*Formations.*	*Subdivisions.*
UPPER SECONDARY STRATA.	Cretaceous System.	600	*Chalk Formation.*	Upper Chalk. Lower Chalk.
		500	*Greensand Formation.*	Upper greensand. Gault. Lower greensand.
	Oolitic System.	900	*Wealden.*	Weald clay. Hastings sand. Purbeck beds.
		400	*Upper Oolite.*	Portland oolite. Kimmeridge clay.
		450	*Middle Oolite.*	Upper calcareous grit. Coralline oolite. Lower calcareous grit. Oxford clay. Kelloways rock.
		400	*Lower Oolite.*	Cornbrash. Forest marble. Bath oolite. Fuller's earth beds. Inferior oolite. Sands.
		1,000	*Lias.*	Upper lias shales. Marlstone. Middle lias shales. Lias limestone. Lower lias shales.
LOWER SECONDARY STRATA.	Poikilitic System.	900	*New Red Sandstone Formation.*	Variegated marls. Variegated sandstone. Conglomerates.
		300	*Magnesian Limestone Formation.*	Knottingley limestone. Gypseous marls. Magnesian limestone. Marl slates. Red sandstone.
	Carboniferous System.*	3,000	*Coal Formation.*	Coal-measures.
		2,400	*Carboniferous Limestone Formation.*	Millstone grit. Great shale. Great scar limestone.
		300 to 10,000	*Old Red.*	Old red sandstone.
	Silurian System.	7,500	*Ludlow Formation.*	Upper Ludlow rock. Aymestry limestone. Lower Ludlow rock.
			Wenlock Formation.	Wenlock limestone. Wenlock shale.
			Caradoc Formation.	Caradoc flags. Caradoc sandstone.
			Llandeilo Formation.	Llandeilo flags.

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* It is proposed by Professor Sedgwick and Mr. Murchison, to include the old red sandstone, and certain slate rocks, constituting a zoological passage from the Silurian to the Carboniferous systems, into a new group, under the name of the Devonian system; and it is highly probable that some such arrangement will, before long, be generally adopted.

STRATIFIED ROCKS.—Continued.

	Systems.	*Thickness.* Feet.	*Formations.*	*Subdivisions.*
LOWER SECONDARY STRATA.	CAMBRIAN SYSTEM.	10,000 at least.	*Upper Cambrian.*	Slates and sandstones. Bala and Coniston limestones.
			Lower Cambrian.	Slates and sandstones.
PRIMARY STRATA.	MICA SCHIST SYSTEM.	Unknown.	*Mica Schist.*	Mica slate. Hornblende slate. Crystalline limestone. Quartz rock.
	GNEISS SYSTEM.	Unknown.	*Gneiss.*	Gneiss. Hornblende slate. Crystalline limestone. Quartz rock.

Imperfection of our present Classification.

It must be remembered, however, that in the present state of our knowledge, attempts to divide the fossiliferous series into a few large groups must be regarded rather as an arrangement of convenience than as having any real foundation in nature; for where the sequence of deposits is unbroken by accidental circumstances, there is a gradual passage by zoological as well as mineralogical characters between the rocks of different systems, as there is between the different members of the same system. It is only where they are found unconformable in position, from the disturbances by which they have been affected, that we can draw those hard lines of distinction which our classifications require. But these disturbances have only been local, though sometimes extending over considerable areas; and when we pass beyond their influence, we find the lines of demarcation obscure, and the arrangement, which elsewhere appeared so clear, becomes embarrassed.

We have already shown how the terms Primary, Transition, and Secondary, were introduced into the science, and why they were retained after the views which gave rise to them were abandoned in consequence of a more enlarged and accurate acquaintance with nature; and we have adverted to the necessity of discontinuing the use of the word Transition, not only because of the erroneous ideas conveyed by it, but because of the latitude with which it had been applied, one geologist making the transition rocks terminate with the grauwacke series, or with the system now called Silurian, another extending it to the old red sandstone, a third including in it the whole of the carboniferous strata, while a fourth considered the old and the new red sandstones as parts of one great system of arenaceous rocks, in which the carboniferous series was a mere local deposit.

The discordance between these different classifications arose from the cause already alluded to, viz., from their having been founded on the study of rocks in different countries where unconformable position had been produced by local disturbances at different epochs. In the present work the term Primary will be restricted to the non-fossiliferous strata, and the term Older Secondary will be used instead of Transition, making it comprise all the fossiliferous strata to the termination of the carboniferous system. Other geologists, among whom is Professor Phillips, include the Cambrian and Silurian systems among the primary rocks, chiefly because up to that point the sequence of deposit appears unbroken by any very extensive movements of disturbance, and because a very general disruption of the crust of the earth appears to have immediately preceded the deposit of the carboniferous system. On the other hand, in the country where the Silurian rocks were first studied, and where they are best developed, they are conformable to the old red sandstone, and carboniferous limestone; while some discordance of position is observable between them and the upper portion of the Cambrian system; and in part of Sweden they are found in the horizontal position in which they were originally deposited, appearing to have been elevated above the waters solely by that gradual process which is now raising or depressing large portions of that peninsula. Considering, therefore, that the most general disruptions of the earth's crust are but of a local nature, we have preferred an arrangement based on certain broad zoological characters; and such appears to be that which classes together the Cambrian, Silurian, and Carboniferous systems,—all characterized by the prevalence of certain extinct genera of molluscs (Spirifera, Producta, Bellerophon, Orthoceras), and of certain extinct families of fishes, by the crustaceous family of trilobites not extending beyond them, and by the peculiar character of their vegetation, when vegetable remains are found in them.* At the same time, it must be owned, that even this division is somewhat arbitrary, since, as we shall see hereafter, the lower part of the system immediately above the carboniferous possesses some zoological characters in common with the rocks of that era.

Cambrian System.

We are indebted to Professor Sedgwick and Mr. Murchison for the separation of that chaotic mass, long known by the vague names of the Transition and Grauwacke series, into systems and formations, defined by peculiar lithological and zoological characters. The results of the researches of the former geologist among the rocks of the lower part of the series are as yet only partially published, but from an examination of those rocks in the south of Scotland, in Cumberland and in North and South Wales, he has arrived at the conclusion, that they are capable of division into two formations comprised in one system, to which he has given the name of the Cambrian, because it attains a great thickness and occupies an extensive area in Wales, where it is seen in contact with the Silurian rocks of Mr. Murchison, which succeed it in the ascending order. The two formations he has named, the Lower Cambrian, or Snowdonian, and the Upper Cambrian, or Plynlymmon formation.

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* Professor Sedgwick and Mr. Murchison propose the term Palæozoic for these rocks.

In the Lower Cambrian formation, which is most extensively developed in the counties of Caernarvon and Merioneth, we meet with the earliest traces of organic remains yet known. In mineral character the system is chiefly argillaceous, consisting of slate of various shades of black, lead-blue, green, and purple, having a jointed structure, and a slaty cleavage transverse to the planes of stratification. The coarse-grained varieties pass into sandstone and conglomerate, and into grauwacke. This last is a rock having an argillaceous base, in which are imbedded fragments of quartz, felspar, mica, jasper, and flinty slate.

These rocks are accompanied by a dark concretionary limestone, at Bala in Wales, and Coniston Water in Westmoreland. Conglomerates, having a porphyritic base, porphyries, amygdaloids, and greenstone, are also associated extensively with the slates, not only in intrusive masses, but also in beds alternating with them, partaking of their flexures and inclination and appearing to be either igneous rocks of contemporaneous origin or metamorphic conditions of the sedimentary strata.

Slaty Cleavage. That fissility and tendency to division by symmetrical joints, which constitute the economical importance of the argillaceous portions of the series as roofing slates, pervade, in different degrees, the entire mass of the Cambrian rocks, and form one of their distinctive characters.

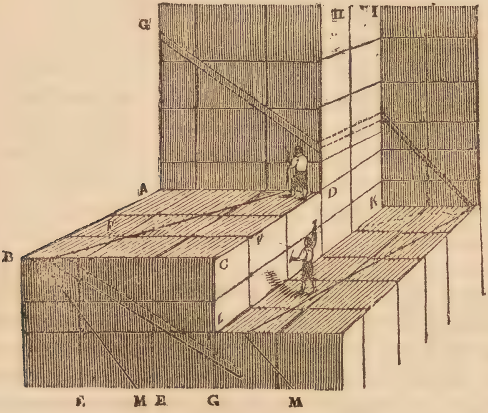
Cleavage, which Professor Sedgwick distinguishes from jointed structure by a capability of indefinite subdivision, appears never to coincide with the true plane of stratification. The planes of cleavage and stratification dip sometimes to the same, sometimes to different, points of the compass; they are inclined to each other, sometimes at an angle of less than 10°, on the average at an angle of 30° or 40°, and in some instances, of 90°. It frequently happens, particularly in the finer argillaceous deposits, that this slaty cleavage has obliterated the laminæ of stratification or rendered them so obscure that they can only be recognised by those stripes, so well known in some of the roofing slates of Cumberland and Wales, formed by alternations of matter differing in colour, mineral composition, or fineness of grain. These stripes are invariably parallel to the alternating masses of sandstone and to beds containing organic remains.

When the cleavage is well developed, its strike coincides with the strike of the beds, that is, with the great axis of elevation; and there are districts in North and South Wales, thirty miles long and many miles in breadth, where the planes of cleavage preserve an undeviating strike and dip, notwithstanding the numberless contortions of the beds.

The cleavage is most prevalent and perfect in the argillaceous, finer-grained, and homogeneous rocks; in the coarser varieties the laminæ and beds of the strata are most distinct.

In the annexed diagram (fig. 58), which represents a stoup, or stage of slate quarry, the plane A B C D is a horizontal joint, the strong lines EE FF are vertical joints running in various directions, GG are bands or stripes of different colour or composition, marking the planes of stratification. The plane C D H I K L is a plane of cleavage, in which, and in which only, the rock is capable of indefinite subdivision as marked by the lines of shading. MM are bevel joints crossing the cleavage obliquely, and making a considerable angle with the horizon.

58



It has been already remarked that the strike of the cleavage coincides, when well developed, with that of the beds or great axis of elevation. This, in North and South Wales and Cumberland, is about N.E. and S.W. The cleavage, however, is subject to slight variations of strike in different quarries, and even in different parts of the same quarry, undergoing a change of direction every time the bed of roofing slate is crossed by one of those veins of quartz, chlorite, carbonate of lime, &c., often containing traces of copper, which are known to the workmen by the name of "posts."

The annexed diagram (fig. 59) exhibits the strike and dip of the cleavage, stratification, and joints, of most frequent occurrence in the Glynyronwy Quarry at Llanberries, with the names by which they are known among the quarrymen. The prevailing joint is the "Back," the average direction of which is at right angles to the cleavage. The "Slant" and the "Bevel" are less common, and their direction and inclination vary in different quarries.

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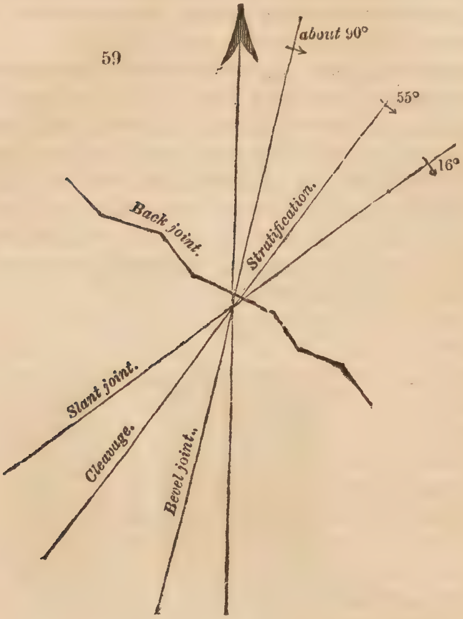

Cleavage and jointed structure appear to be conditions superinduced subsequent to the sedimentary accumulation of the strata, and subsequent also, in many cases, to the movements of disturbance by which they were thrown into an inclined position, for the vertical or nearly vertical cleavage traverses, as was before observed, many alternations of contorted strata, and its parallelism has not been affected by those contortions. It may be considered in a great measure confined to, or more perfectly exhibited and extensively developed, in these older argillaceous rocks.

Imperfect cleavage occurs locally in more modern deposits near their contact with trap dikes and other igneous masses. We may, therefore, consider the slaty cleavage of the Cambrian system, as the result of a more general action of heat on sedimentary rocks, overcoming the original lamination of the deposit, and causing the particles to arrange themselves in a new position.

It has not been produced on an extensive scale in the Silurian, or next system of rocks in the ascending order, nor among more modern formations; and even among rocks of the Cambrian type, slaty cleavage is more prevalent in the lower than in the upper part of the system.

Organic Remains. The rocks of the Cambrian group afford the first undoubted traces of organic remains. They occur at but few points, and in small quantities, amidst a great thickness of sedimentary rocks, extending over a wide area, and this circumstance, connected with the paucity of species where the fossils are in the greatest abundance, appears favourable to the presumption that the absence of organic remains from the older stratified rocks of the mica slate and gneiss systems, is not the effect of any process by which they have been destroyed, and that in the Cambrian rocks we behold the first appearance of organic life upon the surface of our planet. Even the limestones, which, in more modern formations, abound in fossils, contain them but sparingly in the Cambrian system. In Cumberland, organic remains have not been detected in the slates, but they occur in the dark slaty limestone of Coniston Water. In Caernarvonshire they are found in Snowdon, in a coarse slate, and in greater abundance in the Bala limestone. Professor Phillips, who is the latest and best authority on the subject, does not extend the number of species of zoophytes and molluscs observed in the slates to more than twelve, and he has not seen above twice that number from the limestones of Bala and Coniston, and the slates of Cornwall.* They belong, according to the same author, to the genera Cyathophyllum, Terebratula, Spirifer, and Leptæna, or Producta. In the slate rocks of Snowdonia the impressions of shells are found at intervals along the same strike, ranging from Llyn Idwal across the path of Llanberris to Snowdon, and reappearing, on nearly the same line, in a small quarry on the demesne of Boduan, near Pwllheli. In the last mentioned spot, where the extent of rock exposed to view is very small, casts of shells, and sometimes portions of the shells themselves, in considerable quantities, but chiefly of one species, are contained in a light blue crystalline rock, having a rude columnar structure, and divided into globular masses, which weather rapidly in concentric layers on exposure to the atmosphere, so as to assume the appearance of a very friable sandstone. The shells here are full and round, on Snowdon they are much compressed, and at Llyn Idwal the traces are extremely indistinct.

Geographical Extent. Rocks of the Cambrian system are found in the following localities within the British Islands. In Scotland skirting the Grampians, from Stonehaven to Loch Lomond and Loch Long; in the Isles of Bute and Arran, Isla, and Jura; on the northeastern coast in Aberdeenshire, and on the English border, extending from St. Abb's Head to the Mull of Galloway.

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* Lardner's Cyclopedia, Geology, vol. i. p. 128.

They occupy the lake district of Cumberland and Westmoreland, a large part of the Isle of Man, and portions of the Isle of Anglesey. In North and South Wales these rocks extend over a tract between thirty and forty miles broad, bounded on the west by the Menai and St. George's Channel, and on the east by a curved line extending from Orme's Head, in Caernarvonshine, to St. David's Head, in Pembrokeshire. Charnwood Forest, in Leicestershire, is composed of them. A large part of Devonshire, and almost the whole of Cornwall, were till lately supposed to belong to the older part of the slate series, but the recent investigations of Professor Sedgwick and Mr. Murchison have reduced these within narrower limits, and have removed the culmiferous shales and grits of North Devon to the epochs of the coal measures, and the fossiliferous slates and limestones of South Devon (Plymouth, Torbay, Newton Bushel) to that of the old red sandstone. The same may be said of the slate districts of Ireland, where rocks of the Cambrian system occur on both sides of the granite, in the counties of Wicklow and Carlow, as also in the counties of Down, Louth, Armagh, Monaghan, and Cavan, and in those of Cork, Kerry, and Waterford; but the Irish geologists, following the example of Murchison and Sedgwick, appear now inclined, on the evidence of organic remains, to refer a considerable portion of them to the same epochs as those of Devonshire.

Large tracts of the mountainous districts of continental Europe are likewise composed of fossiliferous slates, in Britany, the Ardennes, the Hartz, and Norway; but it yet remains to determine the limits between the Cambrian and Silurian strata, and to ascertain whether those districts afford any more recent slate rocks intermediate, like those of Devonshire, between the Silurian and Carboniferous systems. The same remark applies to the chain of the Atlas, in Africa, the Alleghanies, in North America, and other distant parts of the world, in which fossiliferous slates have been observed.

The annexed diagram (fig. 60) represents the broken and contorted state of the Upper and Lower Cambrian rocks from the Menai to the English border, and their relations to the chloritic slate of Anglesey on the west, and the Silurian and Carboniferous rocks on the east.

Types of the Cambrian Formations. The types of the upper and lower formations of the Cambrian system, deduced from a combination of the phenomena of Wales and Cumberland, the only districts where these rocks abound which have as yet been thoroughly examined, may be stated thus.

Lower Cambrian or Snowdonian Formation.

Wales. The rocks of the greater part of the counties of Caernarvon and Merioneth, consisting of slates of various colours, with cleavage transverse to the stratification, grauwacke, and conglomerates, associated with porphyry and greenstone. The porphyries are frequently interstratified with the slates, and graduate into them and into conglomerates with a porphyritic base. A few organic remains. Thickness unknown, but probably several thousand yards.

Cumberland. The green slates and porphyry rocks of Langdale and Borrowdale, dark flags and slates in the upper part, fine grained green slate in the middle, amygdaloid and fragmentary rocks in the lower part. The slates pass into compact felspathic slate, sometimes porphyritic ; also into granular and concretionary slaty masses, and through them into breccias. The amorphous columnar and prismatic porphyries are arranged in directions parallel to the beds of green slate, and pass themselves into a slaty texture, with a strike and dip parallel to those of the true roofing slate. No organic remains. Thickness at least a thousand yards.

Upper Cambrian or Plynlymmon Rocks.

This formation commences with the dark limestones of Bala and Coniston Water, containing shells and corals. Thickness in Cumberland, about a hundred feet.

Wales. Grauwacke and grauwacke slate, with some beds of conglomerate. Thickness probably several thousand yards.

Cumberland. Houghill and Kentmere rocks ; a mass of grauwacke in the upper part; in the lower, alternations of grauwacke and grauwacke slate. Thickness, full a thousand yards.

In the Cambrian district the green slates and porphyries, answering to the Lower Cambrian or Snowdonian rocks, rest upon a group at least a thousand yards thick, to which Professor Sedgwick has given the name of the Skiddaw rocks. It consists of dark soft slates, destitute of fossils, and containing, in the lower part, crystals of chiastolite, and near the base, hornblende. These slates cover a thin crust of mica slate and gneiss, below which is granite. This chiastolite group appears not to be developed in Wales, unless it be represented by the chlorite slate of Anglesey, some varieties of which pass into mica slate, and others into clay slate.

Fig. 61, which is a section from the centre of the Cambrian district to the coast of Northumberland, exhibits the succession of these different groups, and of the more recent carboniferous and poikilitic rocks.

Similarity of the Cambrian to the Silurian Strata.

The organic remains of the Cambrian system are as yet too imperfectly known to admit of an accurate comparison of them with those of the Silurian rocks. Some of them differ specifically, and a few are generally distinct; but they do not exhibit a difference proportioned to the long interval of time which the great thickness of the Cambrian deposits may be supposed to denote. The fossils of the Silurian strata appear to be distinguished from them, not so much by change of type, as by the greater developements, both as to species and individuals, of forms already existing. The rocks of the two systems may, therefore, be regarded as having been formed under nearly similar conditions. If we inquire what those conditions were, it would appear that the Cambrian rocks were deposited in an ocean destitute of any neighbouring land; for in Britain, if elsewhere, no remains of land plants have as yet been met with, the few organic remains yet found being confined, as we have seen, to zoophytes and molluscs.

Igneous Rocks, and Mineral Veins. From the abundance of porphyry and greenstone alternating with the sedimentary deposits, and passing into them, volcanic ejectments appear to have been of frequent occurrence during this era, spreading sheets of lava over the floor of the ocean. We have, however, from our own observations, reason to think that some of the porphyries of Snowdonia, are metamorphic, if they do not even contain obscure traces of organic remains. The slate rocks have also been pierced by dikes and intrusive masses of igneous matter. In Cornwall, Cumberland, Ireland, the southwest of Scotland, and the Isle of Man, they are in contact with granite, which in Cumberland has sent off veins into the incumbent strata, and must therefore be more recent than the slate. Dikes of porphyry, syenite, and greenstone, have likewise penetrated through the slate, forming overlying masses; and besides this local igneous action, the whole body of these rocks appear to have been subject to a more general heating process, to which we may attribute their subcrystalline character and slaty cleavage. Mineral veins are more abundant in the lower part of the series than in the upper part, and they generally occur in the vicinity of igneous rocks. The slate district of Cumberland produces lead, copper, iron, zinc, and manganese; that of Cornwall, copper, lead, silver, arsenic, and cobalt; but they are not confined to the rocks of this era, for Mr. De la Beche has lately shown, that, in the vicinity of the granite, rich veins of tin are worked in rocks of the carbonaceous series. Anglesey is celebrated for the large mass of copper found in the Parys Mountain, at the junction of the clay slate with the chlorite schist. Snowdonia and Cardiganshire, yield copper

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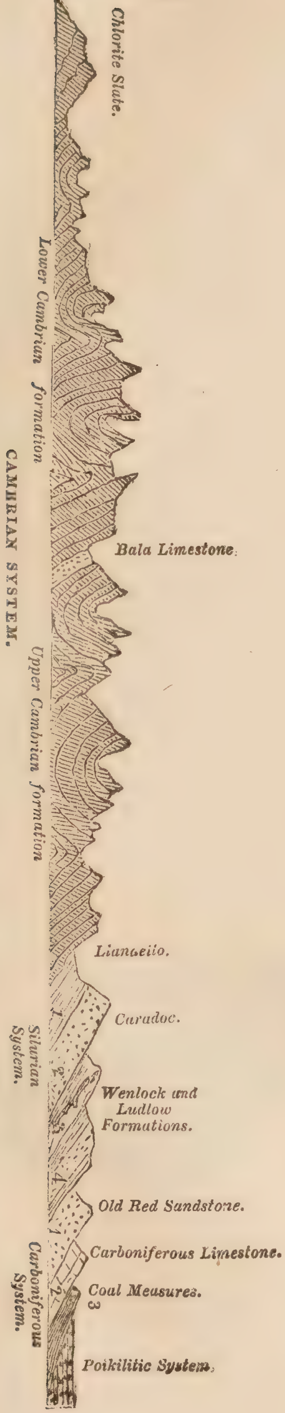
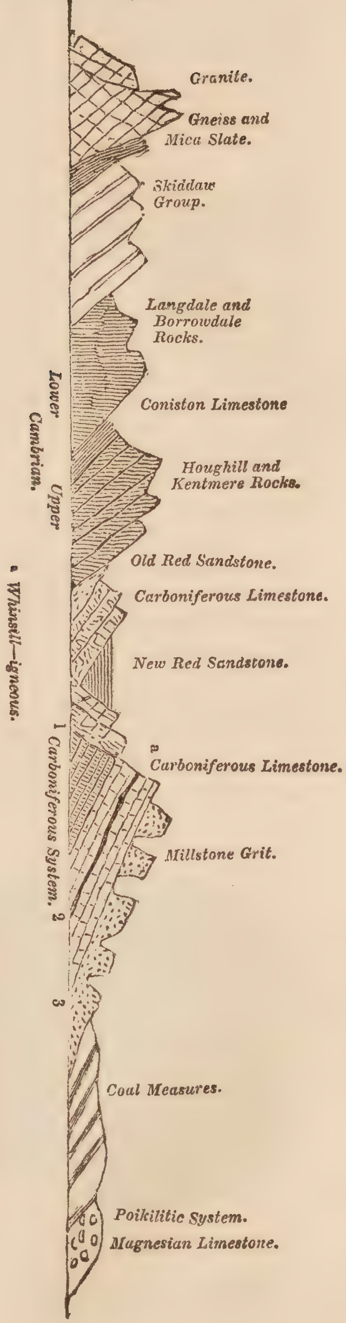

Chlorite Slate.
Lower Cambrian formation
CAMBRIAN SYSTEM.
Bala Limestone.
Upper Cambrian formation
Llandeilo.
1
Caradoc.
Silurian System.
Wenlock and Ludlow Formations.
Old Red Sandstone.
Carboniferous Limestone.
2
Coal Measures.
3
Carboniferous System.
Poikilitic System.

61

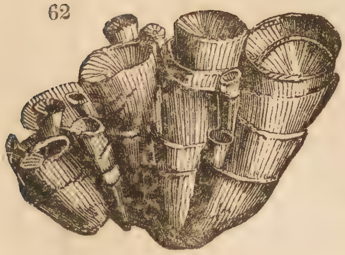

Granite.
Gneiss and Mica Slate.
Skiddaw Group.
Langdale and Borrowdale Rocks.
Coniston Limestone
Lower Cambrian.
Upper
Houghill and Kentmere Rocks.
Old Red Sandstone.
a Whinsill—igneous.
Carboniferous Limestone.
New Red Sandstone.
1 Carboniferous System. 2
a Carboniferous Limestone.
Millstone Grit.
3
Coal Measures.
Poikilitic System.
Magnesian Limestone.

and lead. The slate rocks of the Hartz and Britany are also rich in metals. In all these districts, the productive veins range chiefly east and west, and are traversed by others, called cross courses, which run north and south, or nearly so.

Silurian System.

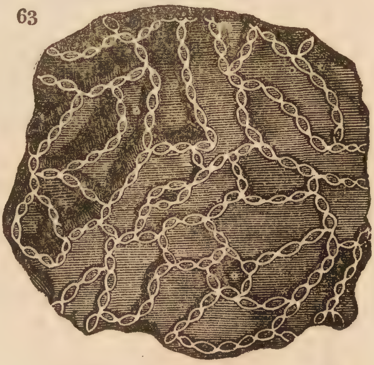
This series of rocks, so ably and elaborately investigated by Mr. Murchison, on the Welsh border, and in South Wales, where it is extensively developed, and where alone it has yet been found complete, consists of a succession of argillaceous, arenaceous, and calcareous deposits, which differ from those of the Cambrian system in the following particulars. The argillaceous rocks are less consolidated, less affected by joints and slaty cleavage, and that only locally, and the laminæ of sedimentary deposits are more perfect. The arenaceous beds partake more of the character of ordinary sandstones than of grauwacke; and the calcareous beds are concretionary and subcrystalline, less earthy than the more modern limestones, less crystalline than those of the gneiss and mica slate systems. Some resemble the flaggy Cambrian limestones, others are more like carboniferous limestone. Considerable varieties also occur in the argillaceous and arenaceous members of the series, the nature of which will appear from the synopsis of the Silurian strata, (p. 222,) exhibiting the matured views of Mr. Murchison, on the subject of the classification of these rocks. It will be seen that he has divided them into principal groups, the Upper and Lower Silurian, each consisting of two formations, named from Ludlow, Wenlock, Caradoc, and Llandeilo, the places where their characters are best exhibited.

62



Cyathophyllum turbinatum.

63



Catenipora labyrinthica.

Organic Remains. The fossils of the Silurian strata are more numerous and diversified than those of the preceding system.

	Formations.	*Thickness.* Feet.	*Subdivisions.*	*Lithological Characters.*	*Organic Remains.*	*Types.*
UPPER SILURIAN.	LUDLOW FORMATION.	2,000	Upper Ludlow Rock.	Slightly micaceous, gray, thin-bedded sandstone.	Corals, Terebratula, Leptæna, or Producta, Orthis, *Pentamerus Knightii*, Lingula, Orbicula, Bellerophon, Homonolotus Knightii.	Ludlow Castle, Aymestry, Woolhope, Sedgeley, west side of the Malvern and Abberley Hills.
			Aymestry Limestone.	Sub-crystalline, gray, or blue argillaceous limestone.		
			Lower Ludlow Rock.	Sandy, liver, or gray, dark-coloured shale and flags, with concretions of earthy limestone.		
	WENLOCK FORMATION.	1,800	Wenlock Limestone.	Highly concretionary, sub-crystalline, gray, and blue limestone.	Corals and crinoidea in great abundance; *Producta depressa*, *Spirifera lineata*, *Euomphilus rugosus*, E. discors, *Orthoceras annulatum*, *Conularia quadrisulcata*, *Calymene Blumenbachii*, C. variolata, Asaphus caudatus.	Wenlock Edge, Woolhope, Dudley, west side of Malvern and Abberley Hills.
			Wenlock Shale.	Argillaceous shale, liver, and dark gray coloured, rarely micaceous, with nodules of earthy limestone.		
LOWER SILURIAN.	CARADOC FORMATION.	2,500	Caradoc Flags.	Thin-bedded, impure, shelly limestone, and finely laminated, slightly micaceous greenish sandstone.	A few corals and crinoidea; *Pentamerus levis*, Orthis, Terebratula, Leptæna, Nucula.	Horderly, Woolhope, May Hill.
			Caradoc Sandstone.	Thick-bedded, red, purple, green and white freestones; conglomeritic quartzose grits; sandy and gritty limestones.		
	LLANDEILO FORMATION.	1,200	Llandeilo Flags.	Dark-coloured flags, mostly calcareous, with some sandstone and schist.	Several trilobites, *Asaphus Buchii.*	Near Shelve, Shropshire, near Builth, Llandeilo.

They consist chiefly of the lower orders of marine animals, and comprise about ninety species of polyparia or corals, and between thirty and forty of crinoidea, both of which are, for the most part, distinct from those of the carboniferous system. The shells at present known, consist of about two hundred species of conchifera (bivalves), sixty of gasteropoda (univalves), and eighty of cephalopoda. The prevailing genera are Leptæna (Producta), figs. 64, 65, 66, Delthyris (Spirifera), Orthis, figs. 67, 68, Atrypa, fig. 69, Terebratula, Pentameris, fig. 70, Orbicula, Lingula, Euomphilus, Oorthoceras, and Bellerophon. Many of these genera are also found in the carboniferous* limestone, but the species are quite distinct. The abundance and variety of the crustaceous family of trilobites, nearly all of them distinct from those of the carboniferous system, is highly characteristic of the rocks of this epoch.

64

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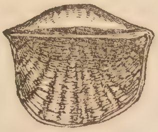

Leptæna transversalis.

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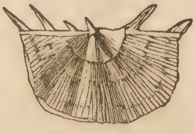

Leptæna lata.

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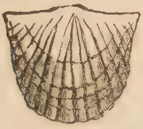


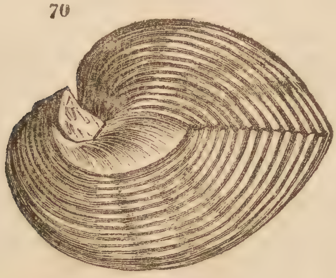
68

Orthis antiqua.

69

Atrypa rotunda.

70



Pentamerus Knightii.—Aymestry Limestone.

The upper Ludlow formation has afforded bones, teeth, and coprolites, or fossil excrement of fishes, which are the oldest known remains of marine vertebrated animals. A few algæ have been found, chiefly in Sweden; but the existence of terrestrial plants in rocks of the Silurian era requires further investigation. The culmiferous rocks of Devonshire, containing some of the plants of the coal measures, and regarded by Mr. De la Beche as part of the Silurian, if not an older system, are now generally admitted to be part of the carboniferous series, altered by the vicinity of the granite of Dartmoor. The floriferous schists, below the culmiferous deposits, appear referable to the era of the old red sandstone, and it is possible that the plants

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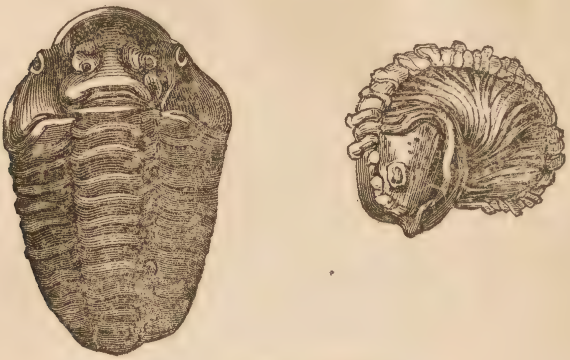
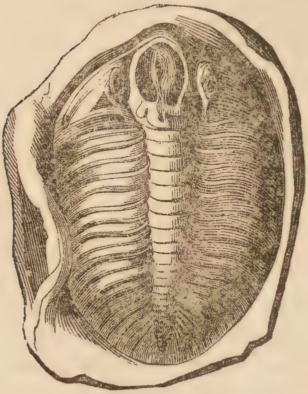
* For figures of the genera Orthoceras, Euomphilus, and Bellerophon, see *The Carboniferous System*, Chap. XIII.

71 72



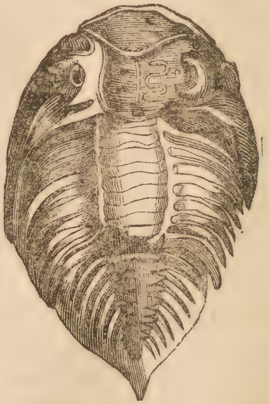
Calymene Blumenbachii.

73



Asaphus Buchii.

74



Asaphus caudatus.

found in the anthraciferous rocks of Baden may be of the same age.

The slate rocks of Devonshire have lately been the subject of much controversy, which may now be considered to have nearly terminated; both parties being agreed as to the order of succession, though they still differ respecting the settlement of the nomenclature. Mr. De la Beche and Mr. Williams at first referred the whole of the culmiferous beds to the lower part of the slate series; but Professor Sedgwick and Mr. Murchison have adduced reasons which may be deemed conclusive, for considering the culm measures as the representatives of the carboniferous system. With respect to the rocks below the coal measures, into which both parties now admit that they graduate, the opinions of Professor Sedgwick and Mr. Murchison have recently undergone a considerable change.

These rocks consist of two calcareous and fossiliferous groups, separated from each other by deposits of vast thickness, very little calcareous, and almost destitute of organic remains. These they referred in 1837, to the upper and middle part of the Cambrian system, with a slight developement in the upper part of lower Silurian rocks; adding, however, that as no fixed line of demarcation could be established between the lower Silurian and upper Cambrian, their zoological contents being very similar, the place of this member of the series must, for the present, be considered provisional. A more extended examination, however, of the organic remains of these fossiliferous slates, has now convinced these authors that they are all more recent than the Silurian strata, and that their fossils constitute a natural group, intermediate in character between the carboniferous and Silurian systems. They, therefore, now regard the slates and sandstones below the culm measures as an enormous developement of the old red sandstone, under a considerable deviation from its ordinary mineral type, a suggestion which originated with Mr. Lonsdale: and they propose the term "Devonian system" for a group including the old red sandstone, constituting a zoological passage from the upper Silurian into the carboniferous system.

Mr. De la Beche, in his recently published map of Devonshire and Cornwall, has substantially adopted these divisions, applying to the culm measures the provisional name of Carbonaceous series, and to the fossiliferous slates of Devon and Cornwall that of Grauwacke. Mr. Greenough, in his new edition of his geological map of England and Wales, follows, in Devonshire and Cornwall, nearly the same boundaries and order of succession as Messrs. De la Beche, Sedgwick, and Murchison, adopting from the former the name of Carbonaceous series for the culm measures, but substituting the term Upper killas for the Devonian system of Sedgwick and Murchison, and Lower killas for the slates inferior to the Silurian, which they have named Cambrian.

Similarity of the Cambrian and Silurian Systems.

The marine remains of the Silurian strata are decidedly distinct from those of the carboniferous system. Their analogy to those of the Cambrian system, as far as the latter are yet known, has already been mentioned as rendering it probable that the deposits of the two eras took place under physical conditions not very different, except that during the formation of the newer rocks they became more favourable to the support of animal life. One of these changes of condition *may* have been the diminution of the internal heat of the globe, which appears to have impressed the slaty cleavage so generally upon the rocks of the older system. If, on further investigation, it shall appear that land plants are inclosed in true Silurian rocks, another of these altered conditions may have been the rise of land, perhaps as small islands in parts of the Silurian ocean, for no traces of terrestrial exuviæ, which become so abundant in the system immediately above the Silurian, have been detected in Britain in that immediately below it.

*Geographical Extent.**

A zone of Silurian rocks, curved first to the south, then to the southwest, and lastly to the west, extends from the Little Orme's Head to St. Bride's Bay. They skirt both sides of the Vale of Clwyd, and extending southwards by Llangollen, and expanding over the Valley of the Severn, border on the south the coal fields of the Plain of Shrewsbury. From Wellington, by Knighton, Builth, Llandovery, Llangadock, and Llandeilo, to the mouth of the Towey, a distance of about 100 miles, the prevailing strike of all the formation is s.w. and n.e.; it then turns westward, and continues with a diminished breadth by Caermarthen and Haverfordwest to St. Bride's Bay.

The great expansion of these rocks between Wenlock Edge and the River Vierniew, in Montgomeryshire, to the northwest of the regular line of bearing on the confines of Shropshire and Hereford, as indicated by the junction of the Ludlow formation with the old red sandstone, arises from the folding over and repetition of rocks of the same age. These reduplications are occasioned by numerous minor axes of elevation parallel to each other, subordinate to the great line of disturbance, and marked in general by eruptive masses of trap, which tilt the strata on their flanks both to the northwest and southeast. On the other hand, whenever the longitudinal influence of these short outbursts has ceased, the Ludlow formation alone is spread out in undulating masses, as in the Forests of Clun, Knuckless, and Radnor, and upon its surface are frequently seen detached and elevated basins of old red sandstone.

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* **Consult Murchison's Silurian System and Proceedings of Geol. Soc.**

In Shropshire, the different formations occupy distinct ridges and valleys, and in their prolongation to the southwest the upper Ludlow rock is uniformly persistent; but in Brecknockshire and Caermarthenshire, from the rapid thinning out of all the formations in their course to the west, and the general absence of the calcareous members, it is only in certain places that these subdivisions can be established; and the great fossiliferous system, which in Shropshire, Hereford, and Radnor, is expanded over so wide an area, becomes compressed into a narrow zone between the old red sandstone and the upper Cambrian slate rocks.

On the eastern side of that undulating mass of old red sandstone, which occupies such an extensive area in South Salop, Hereford, Brecknock, and Monmouthshire, the Silurian strata emerge from beneath it in the Abberley Hills, and on the flanks of the Malverns, also near Usk, in Monmouthshire, in the Woolhope valley of elevation, and in May and Huntley Hills, in Gloucestershire; the Ludlow and Wenlock formations being the most persistent, and usually occupying, as in Shropshire, two distinct ridges, though on a smaller scale. The mean direction of the strata on this eastern side of the old red sandstone is north and south, but subject to many local variations, curvatures, and faults.

Dudley Castle Hill, Sedgeley, and the Wren's Nest, are composed of Silurian rocks, rising in the midst of the South Staffordshire coal field, in short and narrow anticlinal ridges, which range north and south, the coal strata resting against them at a considerable angle.

Professor Phillips has found traces of the upper Ludlow rocks near Kirby Lonsdale, in Westmoreland, and of the lower Ludlow in Ribblesdale, in Yorkshire. Silurian strata are supposed to accompany the Cambrian rocks in the clay-slate districts of Ireland, but the boundaries of the two systems in that country have not yet been determined. On the continent of Europe fossils of this era are found at Christiana in Sweden, in the Eifel, the Hartz, and Britany. Mr. Strickland describes them as occurring on the shores of the Bosphorus. In North America they have been observed on the borders of Lakes Huron and Superior.

Igneous Rocks.

The Silurian strata of the Welsh border have been extensively penetrated by numerous eruptions of igneous matter, forming the axes of ranges of hills which rise from 200 to 300 feet above the sea level (the prevailing strike being N.E. and S.W.), such as, in Shropshire and Montgomeryshire, the Wrekin and Lilleshall Hills, Caer Caradoc, the Longmynd, and Haughmond Hills, the mining district of Shelve, the Stiper Stones (a remarkable serrated ridge of metamorphic quartz rock,) and the Breiddin Hills; in Radnorshire, the group of old Radnor, with the Llandrindod and Builth group; several of the hills of Brecknockshire and Caermarthenshire; and the Abberley and Malvern Hills, in Worcestershire. The trap rocks are of a very variable character, passing by insensible gradations into one another. In the Wrekin and Lilleshall Hills, compact felspar prevails; in Caer Caradoc many varieties of felspar rock, syenite, and greenstone, also amygdaloid containing actinolite; the Longmynd and Haughmond Hills afford varieties of greenstone, porphyry, and amygdaloid; the mining district of Shelve, greenstone, compact felspar, concretionary felspar, and amygdaloid; the Breiddin Hills, porphyries, greenstones, and much concretionary rock. The old Radnor group is distinguished from the others by hypersthene passing into fine-grained greenstone. The Llandrindod and Builth group, and the trappean hills of Brecknockshire, contain greenstone, porphyries, and compact felspar. The Malverns and Abberley Hills consist chiefly of syenitic rocks.

These trappean masses have occasioned great alterations in the sedimentary rocks with which they are in contact. Sandstones of the Caradoc formation are converted into quartz rock, shales are indurated and changed to the state of Lydian stone, limestone becomes crystalline, calcareous flags are changed into a substance resembling white porcelain, coatings and nests of anthracite are generated, and also minute veins of the sulphurets of copper, iron, and lead, carbonate of lime, and sulphate and carbonate of baryta. Where the trap rocks traverse calcareous strata, imperfect serpentine sometimes occurs near the point of contact. In the Malvern Hills grauwacke strata assume the characters of chlorite and mica schist, and others that have not been altered have been thrown into a retroverted position by the igneous rocks.

Mineral springs occur along many of these axes of elevation, and in the mining districts of Shelve, and in the vicinity of Llandovery, the ores of lead appear to be associated with and dependent on the presence of the igneous rocks; a fact in accordance with the general theory of M. Necker on this subject, and an example, on a small scale, of phenomena which occur more extensively in the Cambrian rocks of Cumberland and Snowdonia, and in most other mineral regions.

Besides these masses of igneous matter which have burst through the Silurian deposits, producing great derangement, fracture, and alteration in the beds which they traverse, there are indications of igneous action contemporaneous with the formations of the strata. Beds, interstratified with the sedimentary deposits, are found in a variety of places enumerated by Mr. Murchison, which, although aggregates of compact felspar with a concretionary structure, contain organic remains; others graduate into a class of rocks containing organic remains imbedded in a base of true volcanic matter. These, to which he has given the name of Volcanic sandstone, appear to be sedimentary deposits, composed of ashes of different degrees of fineness, given off during submarine volcanic eruptions. These conformable alternations of trap with sedimentary rocks, afford analogies to the repetitions of volcanic ejectments and marine deposits which are now taking place in the bed of the sea, and they explain the manner in which much of the porphyry and greenstone slate of the older Cambrian system was arranged in parallel beds among the sedimentary accumulations of that epoch.

CHAPTER XII.

CARBONIFEROUS SYSTEM.

General characters.—Formations—old red sandstone (Devonian system)—carboniferous limestone—its subdivisions—northern and southern types—coal formation—extent of old red sandstone and carboniferous limestone in Great Britain.—Coal fields of England—I. Northern district: 1. Coal field of Northumberland—its principal seams—splitting of the High Main coal by the Heworth Band—dikes—fire-damp—produce and probable duration of this coal field—2. Coal field of Yorkshire and Derbyshire—3. of North Stafford—4. of Lancashire—5. of Whitehaven. II. Central district: 1. Coal field of Ashby de la Zouch—2. of Warwickshire—3. of South Staffordshire—the Ten yard coal—Flying Reed—absence of carboniferous limestone—extension of the coal field beneath the poikilitic sandstone. III. Western district: 1. Coal field of North Wales—2. of Coalbrook Dale—freshwater beds—3. Coal field of the Plain of Shrewsbury—4. Clee Hills—5. South Wales—6. Forest of Dean—7. Somersetshire and Gloucestershire.

CARBONIFEROUS SYSTEM.

Synonyms. 1. Old red sandstone, English authors. *Grès rouge intermediaire,* French. *Jüngeres grauwackengebirge,* German. 2. Carboniferous limestone; Mountain limestone; Encrinal limestone, English authors. *Calcaire carbonifere; Calcaire anthraxifere; Calcaire de transition,* French. 3. Coal measures, English authors. *Terrain houiller,* French. *Steinkohlen-gebirge,* German.

General Characters.

We have now reached, in the ascending order, the base of the carboniferous system, one of the most interesting groups of rocks presented to our consideration, whether we regard its economical importance or the abundance of its organic remains, and the curious views which they disclose respecting the physical condition of these northern regions during its formation.

This system is of great thickness, extending in its fullest developement to about 7000 feet, exclusive of the old red sandstone, and exhibiting throughout the strongest proofs of slow and successive deposit, in the abundance and perfect condition of its fossils, in the repeated alternations of strata of different mineral composition, and in the bedded and laminated structure of its component members.

Rocks of this series are extensively but irregularly distributed over the northern regions of Europe, and also over North America and Australia. Small patches occur in Belgium, France, Germany, Poland, and Russia. They occupy large areas in Ireland and the south of Scotland; but valuable beds of coal are no where so largely developed as in England and Wales, where the rich deposits of that mineral, with its accompanying ironstone, contribute so much to the commercial prosperity and political power of Britain.

The carboniferous group is generally found in detached masses on the sides of mountains of older rocks previously elevated; but there are cases where this discordant position is not met with, but a gradual passage is observable from the upper members of the Silurian group into the lower part of the carboniferous system, and it may be expected, as we have already hinted, that, as the examination of the grauwacke series proceeds, a complete zoological passage will be established from that group into the carboniferous.

In England, where the old red sandstone is in general unconformable to the slates, and conformable to the carboniferous limestone, it has long been regarded as the lowest member of the carboniferous series; on the continent, where it is of rare occurrence, and then accordant in position to the slates, it is classed as the upper part of the grauwacke or transition series; and from recent discoveries, it appears that this is the true arrangement. Its organic remains only occur locally, and were till of late little known; but as our knowledge of these was extended, chiefly through the labours of Mr. Murchison, it became evident that they constituted a group distinct from the fossils both of the carboniferous and Silurian eras, and the more recent researches of that geologist and Professor Sedgwick have rendered it highly probable, that the old red sandstone is in reality the abnormal representative of a large group of slates and sandstones with courses of limestone, which connect zoologically the Silurian and carboniferous rocks, and are as much entitled to the rank of a system as either of them. For this group they have proposed the name of Devonian system. At the same time, until the views of these authors shall be fully matured by the examination which they have undertaken of the transition rocks of Continental Europe, and till they shall have received the sanction of the majority of geologists and of time, it does not appear desirable in an elementary work to depart from the established arrangement, however imperfect, in favour of a new classification and nomenclature which may perhaps yet require modification.

The name by which these rocks shall be designated is not of much importance, so that it be one that shall be generally adopted. The term Grauwacke series having been established, upper, middle, and lower grauwacke would perhaps have been the best names for the three groups into which it now appears that the transition rocks of Werner are divisible; but, since the terms Cambrian and Silurian have been introduced into the science for two portions of the series, and have acquired considerable currency, consistency seems to require that the third group should receive a name derived from some locality, whatever it may be, which shall be found to afford the best type of it.

Preparing the student then for the intercalation of a new system of rock between the carboniferous and Silurian, we shall not for the present attempt to remove the old red sandstone from the carboniferous group with which it has been so long associated.

Formations.

Arenaceous, argillaceous, and calcareous rocks form the mass of the series, associated with beds of coal, ironstone, and chert. It may be divided into three formations, so long at least as the old red sandstone is classed with it, possessing general peculiarities of mineral structure, but exhibiting in detail many local variations.

These formations, beginning with the lowest, are,—

I. *The Old Red Sandstone*, consisting chiefly of arenaceous deposits, but alternating occasionally with shales and limestones. The organic remains, which however are rare, consist of plants, marine shells, and fishes. Thickness, 300 to 10,000 feet.

II. *The Carboniferous Limestone.* A great mass of limestone, sometimes alternating with beds of shale and sandstone, and containing beds of coal. Fossils wholly marine. Thickness, 900 to 2400 feet.

III. *The Coal Formation*, composed of numerous alternations of coal, sandstone, and shale, accompanied sometimes by beds of ironstone. The fossils consist chiefly of remains of vegetables. The shells are, for the most part, those of the sea, but mixed with a few analogous to the freshwater genus unio, which may have been deposited in estuaries or at the mouths of rivers. Thickness, 600 to 3000 feet.

I. *The Old Red Sandstone.*

This rock varies considerably in its characters. Its most distinguishing features are the absence of coal, the scarcity of calcareous strata, and its colour, which is usually iron-red, dark-brown, or gray, changing to red. Except in this last respect it bears a close resemblance to the millstone grit, and may be regarded as the lowest member of a long series of arenaceous deposits. From the new red sandstone above the coal measures, which constitute the upper member of this arenaceous series, it is not easily distinguished mineralogically, except by its greater consolidation.

The most common form of the old red sandstone is that of a coarse-grained micaceous sandstone, composed of abraded fragments of quartz, mica, and felspar, and containing fragments of clay slate, flinty slate, &c. It sometimes passes into a coarse quartzose conglomerate, and, on the other hand, in its lower regions, it occasionally becomes a fine-grained and schistose micaceous sandstone, divisible into flags and coarse roofing slates, in planes parallel to the laminæ of stratification. Sometimes, also, it alternates with thin beds of concretionary limestone and with argillaceous strata, both soft and indurated.

The old red sandstone, as well as the carboniferous limestone, is occasionally absent, and the coal measures rest immediately on older rocks, on the Silurian strata for instance, in the district of Dudley, and on mica slate and granite, in Central France.

On the confines of Wales the old red sandstone becomes a complex deposit, composed of argillaceous, siliceous, and calcareous alternations, conformable to and graduating into the Silurian rocks.

The following subdivisions have been established by Mr. Murchison, in Herefordshire and the adjoining counties, in the descending order. The total thickness he estimates at 10,000 feet.

1. Red quartzose conglomerate, overlying thick-bedded sandstone, and passing downwards into chocolate-red and green sandstones and marl. No fossils.

2. Cornstone and marl, impure concretionary limestones, with mottled red and green argillaceous marls and sandstone. Remains of fishes of the genus cephalaspis and onchus.

3. Tilestone, laminated, hard, reddish or green, micaceous or quartzose sandstones. Remains of molluscs and fishes.

On the borders of the mountain districts of Cumberland and Scotland the old red sandstone chiefly appears under the form of large masses of coarse conglomerate, composed of fragments derived from the older rocks of the immediate vicinity. On the northern and eastern coasts of Caithness these conglomerates are developed on an enormous scale, and form a complex group, consisting, in the upper part, of

1. Red, brown, and variegated sandstones.

2. A great formation, composed of alternations of sandstone, siliceous and calcareous, siliceous schist and flagstones, dark foliated bituminous limestone and schist. Fishes in abundance.

3. Conglomerates, containing subordinate masses of red sandstone, red marl, and calcareo-siliceous flagstone. On the southern shores of the Murray Frith these bituminous schists are in some degree replaced by concretionary limestones, resembling the cornstone of Herefordshire.

On the coast of Forfarshire, where the old red sandstone attains a thickness of many thousand feet, it exhibits a series somewhat similar to that of Herefordshire:—

1. Red and mottled marls, cornstone, and sandstone.
2. Conglomerate of great thickness.
3. Highly micaceous and slightly calcareous tilestones and paving-stone. Fishes of the genus cephalaspis.

II. *The Carboniferous Limestone Formation.*

No part of Europe affords so large an extent, and so complete a series of this group, as the British Islands. It is best studied in the escarpments of the Great Penine chain, which ranges down the centre of England from the Scotch border to the banks of the Trent. It is seen in that chain under two different characters, indicating the changing conditions of sea and land during its deposition.

These may be called its northern and southern types; to the one or the other of which different portions of this formation, in England, Scotland, Ireland, and on the continent of Europe, may be referred. To the southern type belong the carboniferous limestone of South Wales, Derbyshire, and South Yorkshire. In this, its most simple form, it consists of three members, included between the old red sandstone, (when that rock is present,) and the coal formation.

These three members, beginning with the lowest, are,—

1. *The Carboniferous Limestone,* a great calcareous mass, almost wholly free from alternations of shale and sandstone; in colour usually gray, varying from nearly white to black, sometimes yellowish or blue; in texture compact, and traversed by veins of calcareous spar. It is also granular and crystalline, affording good marble; sometimes, though rarely, oolitic. When pure, it contains 96 per cent. of carbonate of lime; but passes by admixture of other substances, into magnesian, ferruginous, and bituminous limestone. It is in some places destitute of organic remains, in others almost wholly composed of them; containing stems of encrinites in such abundance as to have obtained the name of encrinal limestone. One of its characteristics is the prevalence of caverns, fissures, and subterranean rivers, particularly in its thick-bedded lower part.
2. *Great or Limestone Shale.* A thick mass of bituminous shale, containing, locally, bands of black limestone and nodules of ironstone.
3. *Millstone Grit.* A quartzose sandstone, consisting of particles of various sizes, often sufficiently large to impart to it the character of a conglomerate. In its more complex form, the sandstone occurs in one, two, or three masses, with shales, and thin beds of coal of indifferent quality.

Southern Type. Of these three terms, then, the carboniferous limestone formation consists in South Wales, Derbyshire, and Yorkshire; and in these three localities they agree in containing no workable beds of coal, which are exclusively confined to the alternations of shale and sandstone, surmounting the millstone grit. They differ in the following particulars: in South Wales, where the old red sandstone below them is so largely developed, the millstone grit and limestone shale are comparatively thin. In Derbyshire, where the old red sandstone is almost, if not wholly absent, the millstone grit group becomes of a greater thickness and more complex character; and the limestone shale contains subordinate masses of a peculiar, thin-bedded, and somewhat argillaceous limestone, but no coal. In South Yorkshire the deposits of the carboniferous limestone formation greatly resemble those of Derbyshire, except that the millstone grit becomes more complicated with alternations of shale and sandstone, and contains a few thin seams of coal. The limestone likewise, hitherto an undivided mass, begins to show some slight alternations of shale.

Northern Type. North of a line drawn from Jerveaux Abbey on the Yore, by Kettlewell and Malham to Lancaster, the members of the carboniferous limestone formation assume their northern type; characterized by the calcareous portion being divided by alternations of shale and sandstone, and by the occurrence of beds of workable coal below as well as above the millstone grit,—the coal gradually descending in the series as we proceed northwards.

First, the great shale and the upper part of the limestone pass into each other, and form a complex deposit, in which five groups of limestone strata, remarkable for their continuity and thickness, alternate with masses of sandstone, containing impressions of coal plants, and with three or four beds of coal, which are worked for home consumption. To this group, Professor Phillips has given the name of Yoredale rocks.

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Actinocrinus 30-dactylus.

The lower, or great scar limestone of Sedgwick and Phillips, next becomes divided in a similar manner. In its escarpments in Yorkshire, as far north as Ingleborough, it manifests no traces of arenaceous or argillaceous alternations, agreeing in this respect with its sections as seen in Derbyshire; but in its further range northwards from Stainmoor, through Cross Fell, to the borders of Northumberland, its upper part becomes divided by thick masses of sandstone and carbonaceous shale, till it gradually passes into a complex deposit, undistinguishable from the rocks of the Yoredale series. The coal beds of that series become at the same time more largely developed; some of them, on the northern border, attaining a thickness of four feet, and being worked to a considerable extent. Further north, the sandstones and shales, alternating with the limestone, expand more and more, the calcareous strata at the same time becoming thinner; so that from Bewcastle Forest, along the skirts of the Cheviots and the valley of the Tweed, the carboniferous limestone loses all its original southern features, and assumes that of a coal formation, the seams of coal thickening with the increase of sandstone and shale, till, in the valley of the Tweed, there is, almost on the parallel of the great scar limestone, a coal field, with five or six seams of workable coal, wrought not only to supply a local demand, but for shipment to the metropolis.

This graduation of the limestone upwards into the coal formation, is accompanied by a similar graduation downwards into the old red sandstone; for alternations of limestone with beds of shale and sandstone, all tinged red by oxide of iron, take place in its lower part. There is not, however, that complete passage into the old red sandstone which is seen in Herefordshire; for on the Scotch border, and the flanks of the Cheviots, and of the Cumbrian mountains, that rock occurs chiefly under the form of the coarse conglomerates already noticed, composed of the detritus of the neighbouring mountains. Pebbles and boulders derived from the same source occur in the lower part of the limestone.

The importance of the diffusion of coal and vegetable remains, through the inferior as well as upper members of the carboniferous system of the north of England, in explaining the source from which the coal strata were derived, and the changes which have taken place in the distribution of land and sea during their formation, will be hereafter adverted to.

III. *The Coal Formation.*

The coal formation, or upper part of the carboniferous system, consists of alternations, frequently and indefinitely repeated, of argillaceous and arenaceous strata, with many beds of coal and some ironstone.

Coal, which consists principally of carbon, and affords evidence of being composed of accumulations of vegetable matter, is distinguished into three kinds, according to the proportion of bitumen contained in it.

1. *Caking coal* contains about 40 per cent. of bitumen; it swells and agglutinates in burning, emitting much smoke, which inflames at a sufficiently high temperature. Most of the coal of Northumberland and Durham is of this description.

2. *Cannel* or *Parrot coal,* contains 20 per cent. of bitumen, in-

flames readily, decrepitates in burning, and does not agglutinate. It prevails in Lancashire and in Scotland.

3. *Stone coal*, culm, or anthracite, is composed almost entirely of carbon and earthy matter, with scarcely any bitumen. It burns with little or no flame, and does not agglutinate. The coal of South Wales and Kilkenny is of this kind. The arenaceous and argillaceous beds interstratified with the coal are known in the collieries by various local names. The following are those in most general use:—

Grit, a coarse sandstone or conglomerate.

Freestone, a sandstone of a loose open texture.

Hazle, a compact close sandstone.

Calliard, a fine-grained compact sandstone.

Flagstone, a sandstone laminated by mica or carboniferous matter.

These are of various colours, white, brown, gray, greenish, yellow, or red, and yield whetstones and grindstones, as well as paving and building stones.

The argillaceous strata, when much laminated, are known by the names of *plate*, when less so by that of *shale*, when unlaminated they are called *clunch*, or *bind;* they are usually bituminous, and their prevailing colour is black, or various shades of blue or gray. In the Northumberland coal fields *post* is the general name for sandstone or grits, and *metal* for shales, which, when indurated, are called *stone metal.*

Ironstone occurs among the strata of the coal formation as a carbonate of iron mixed with clay, both in continuous beds and as irregular layers or nodules, the latter frequently formed round organic bodies. It yields, on an average, about 30 per cent. of iron; it frequently exhibits a single concretionary structure, known as "cone in cone," or conical ironstone.

The total thickness of coal in the coal fields of Great Britain is forty-five to sixty feet, in more than twenty beds, varying in thickness from a few inches to two yards and more, but all these seams cannot be regarded as continuous over an entire coal field, some of them arising from the splitting or division of larger seams, by the interposition of argillaceous and arenaceous strata; and the distance of a mile or two often exhibits great changes in the number and quality of the seams—a fact of considerable theoretical importance in estimating the circumstances under which the coal strata were deposited.

Geographical Extent of Carboniferous Rocks.

In describing the superficial extent of the rocks of the carboniferous system in the British Islands, we shall first trace the range of the lower members of the series, namely, the old red sandstone and carboniferous limestone, in Scotland and England, and then proceed to the detached coal fields surmounting the millstone grit; noticing, lastly, the distribution of the entire carboniferous series in Ireland.

Old red conglomerates skirt the western coast of Scotland, appearing in the Isles of Rum and Skie, and on the mainland at Applecross, and extend in interrupted patches to Cape Wrath and Port Skerry. From the latter place they expand over the interior, rising into a mountain range, which is continued to the Ord of Caithness, and attains an elevation of 3500 feet. These conglomerates with calcareo-bituminous schists, containing the remains of fishes, are largely developed on the shores of the Pentland and Murray Friths, reappearing in the lofty cliffs of the Orkneys, and gradually thinning off on the eastern shores of the Murray Frith till they are lost in Cullen Bay in Banffshire. They extend by Elgin and Inverness up the great valley of the Caledonian Canal to Meale Favournie. A broad zone commences on the coast of Forfarshire between Stonehaven and the Frith of Tay, and stretches across the interior on the southern flanks of the Grampians to the Frith of Clyde, both sides of which are bordered with old red sandstone, which is seen in Bute, and about Largs, and in the Isle of Arran and Cantire. It is likewise found in the northern part of Fife cropping out from beneath the coal strata, and on the shores of the Frith of Forth skirting the northern flanks of the Lammermuirs (with some interruptions from masses of igneous rocks), from Dunbar on the east to beyond the source of the River Ayr on the west. It occurs in detached portions in Kircudbright and Dumfries, and covers a considerable area in the valley of the Tweed, where the alternations of red sandstone and shale with the lower part of the carboniferous limestone have already been noticed. It is seen, under nearly similar circumstances, in some of the escarpments of the Penine chain near Dufton, in the valley of the Lune, and at several other points emerging from beneath the carboniferous limestone which flanks the lake district of Cumberland and Westmoreland.

In South Wales the old red sandstone largely developed, with argillaceous and calcareous alternations, is extensively spread over the counties of Hereford, Brecknock, and Monmouth, and extends through Caermarthenshire in a narrow band between the region of Silurian rocks, and the carboniferous limestone which borders the great coal field of South Wales. It also occupies a considerable portion of Pembrokeshire on either side of Milford Haven, south of which it is broken into two narrow bands ranging nearly east and west by an anticlinal ridge of Silurian rocks heaved up through the midst of it. Detached portions also occur at the Worm's Head in Glamorganshire, and on the opposite side of the Bristol Channel beneath the limestone of Bristol and the Mendip Hills. Near Bristol beds of red sandstone alternate, as in the valley of the Tweed, with the lower part of the carboniferous limestone.

The developement of the carboniferous limestone is very slight in Scotland, being confined to alternations of calcareous beds containing marine remains with seams of coal, in the great coal field of the valleys of the Forth and Clyde, which belongs to the lower part of the carboniferous series. In England, the largest tract of carboniferous limestone is situated on the confines of Northumberland, Durham, and Yorkshire. It commences near Eyemouth, in Scotland, running along the coast to the river Coquet, skirting the Tweed and the porphyritic range of the Cheviots, and extending along the flanks of the slate district of the south of Scotland to the banks of the Liddel near Langtown. The boundary then turns S.E. to Brampton, and thence, following the escarpments of the Penine chain through Cross Fell and Stainmoor Forest to the vicinity of Kirby Stephen. At this point a zone is thrown off, which encircles the Cumbrian mountains, continuously on the north, and in irregular patches on the south about Ulverstone and Kendal.

Again, following the escarpments of the Penine chain, which from Kirby Stephen range nearly S.W. by S., the carboniferous limestone abuts against the slate mountains of the lake district, being separated from them by an enormous fault, which has elevated the Penine chain, and which, along its whole course from Brampton to Kirby Lonsdale, has caused a relative displacement of the strata on the two sides of it for a length of fifty miles, and, in one part, to the extent of more than 3000 feet.

From Kirby Lonsdale, the boundary of the carboniferous limestone turns E.S.E. to the Ribble, following another fault, called the Craven fault; which has exposed to view, in Ribblesdale, a narrow band of slate rock running for about fifteen miles between two bands of limestone, that on the east being the continuous edge of the horizontal beds in the elevated Penine region, that on the south being a narrow line of those rocks set on edge, and dipping violently to the south. From the southern extremity of this district of Ribblesdale slate, near Settle, the western boundary of the limestone district coincides nearly with the line dividing the counties of York and Lancaster. The limestone extends into the latter county, about five miles south of Clitheroe, and then turns E.N.E. to the banks of the Wharfe.

We have now traced the western limits of that continuous band of carboniferous limestone, which extends from the Scotch border into the centre of England. Throughout the greater portion of that district the lower or scar limestone is exhibited in the western escarpments of the Penine chain, or in the transverse valleys which intersect it. The upper parts of the limestone and millstone grit occupy the summits of those escarpments, or compose the central ridges; the whole being covered on the east by the coal fields of Durham, South Yorkshire, and Derbyshire.

The eastern boundary, or that dividing the limestone from the great shale and the millstone grit, is less easily defined, by reason of the passage of the different members of the carboniferous limestone formation into each other, which we have described as taking place in the district now under consideration. The greatest breadth of the calcareous portion of the carboniferous system of the north of England, including the upper and lower limestones and the Yoredale rocks, with their associated coal, is between the Tweed and the Coquet, the eastern boundary extending nearly southwest along the banks of the Tyne to near Hexham, and thence west to Haltwhistle. From this point the limestone district contracts in the narrow band already traced, as exhibited in the escarpments of the Penine chain, and then expands again into a broad but irregular tract, in which the summits of the hills are capped by millstone grit, the limestone being displayed at their base and in the intervening valleys. South of Clitheroe and Skipton the limestone sinks beneath a continuous mass of the millstone grit, and beneath the coal field of Lancashire.

Further to the south, two insulated tracts of carboniferous limestone have been protruded along an anticlinal axis, through the millstone grit; one the small patch on the northeastern skirts of the Lancashire coal field, the other, a large and elevated region, constituting the Peak Forest, or lead district of Derbyshire. The surface of the latter is very irregular, being divided by numerous narrow valleys or broader dales, celebrated for their striking and picturesque scenery. The total ascertained thickness of this calcareous tract exceeds 1000 feet, consisting of 750 feet of limestone, divided by 252 feet of amygdaloidal trap, locally called toadstone, in four beds of variable thickness. The rock on which this formation lies is nowhere exposed in any natural section neither has the lower limestone been sunk through in any mining operation. The limestone, with its superincumbent shale and millstone grit, sinks on the south beneath the poikilitic formation of Central England.

Bands of carboniferous limestone are found on the skirts of the clay-slate district of North Wales, ranging along the shores of the Menai, from the neighbourhood of Caernarvon to that of Bangor; also in a depression parallel to those Straits, which extends through the centre of Anglesey, from Malltraeth to Redwharf Bay, and in the N.E. extremity of the island at Penmon. Recommencing on the opposite coast of Caernarvonshire, at the Great Orme's Head, the limestone skirts the sea-coast by Abergele, and both sides of the Vale of Clwyd, constituting the lead district of the counties of Denbigh and Flint, and extends in a narrow promontory to Llanermynach, a little south of Oswestry.

The coal fields of South Wales are surrounded by a band of carboniferous limestone, which stretches on the north and east from Narbeth, in Pembrokeshire, by Abergavenny and Caerphilly, and thence on the south by Bridgend, Swansea, and Tenby, to Milford Haven. It appears also on the western side of the Bristol Channel, on the banks of the Wye, and in detached portions on the opposite shores of the estuary, about Bristol and the Mendip Hills.

Professor Sedgwick and Mr. Murchison refer the limestone of Barnstable Bay, in Devonshire, to this formation. Some beds of limestone, which occur below the coal measures of the Clee Hills in Shropshire, are supposed to be a slight developement of the carboniferous limestone.

The millstone grit is found, in its greatest extent, and most complete developement, in the north of England, where it occupies a wide area, forming the western summits, the central ranges, and the eastern slopes of the Penine chain. It extends continuously s.w. by w. from the banks of the Coquet to those of the Tyne. From that river to near the mouth of the Ribble it is found chiefly in insulated masses, constituting the summits of the hills. Larger tracts of it extend, the one over Bolland Forest, the other from the vicinity of Ormskirk to the banks of the Yore, near Middleham ; dipping on the east under the magnesian limestone between Aberford and Masham, and under the Yorkshire coal field, by Leeds, Bradford, and Huddersfield. South of the last-mentioned town, it ranges in a southern direction down both sides of the limestone district of the Peak Forest, separating it from the coal field of South Yorkshire and Derbyshire on the east, and from those of Manchester and North Staffordshire on the west.

In North Wales the millstone grit occurs under the form of beds of shale and sandstone, interposed between the carboniferous limestone and the coal formation.. It appears in the coal field of South Wales as beds of conglomerate and coarse grit, observable near Merthyr, and the head of the Neath Valley on the north, and near Bridgend and Caerphilly on the south. In the Forest of Dean it is known as the " Farewell Rock ;" and in the basin of Gloucestershire and Somersetshire, as beds of conglomerate and hard cherty sandstone, often highly ferruginous, which may be seen at Brandon Hill, near Bristol, and, resting on limestone, on either side of the gorge of the Avon, near Clifton.

Coal Fields of England.

In describing the geographical distribution of coal through England and Wales, we shall follow the arrangement of Conybeare and Phillips ; dividing them into—

I. The coal fields north of Trent surrounding the Great Penine chain, containing—
  1. The coal field of Northumberland and Durham.
  2. That of Yorkshire, Nottingham, and Derbyshire.
  3. That of North Staffordshire, sometimes called the Pottery coal field.
  4. That of Manchester.
  5. That of Whitehaven.

II. The central coal district, comprehending the coal fields—
  1. Of Liecestershire.
  2. Of North Staffordshire.

III. The western coal district, subdivided into—
  1. The northwestern, containing the coal fields of North Wales.
  2. The western containing those of the Plain of Shrewsbury, of Coalbrook Dale, and the Clee Hills.
  3. The southwestern, comprising the coal fields of South Wales, of the Forest of Dean, and of Gloucestershire and Somersetshire; to which, according to Murchison and Sedgwick, we may add the culmiferous deposits of North Devon.

Although the coal of England is derived from so many insulated districts, or basins as they are sometimes called, many circumstances render it probable that they were once continuous on the bed of the sea, and that their separation has been caused by dislocations subsequent to the formation of the strata. Some of them, as the coal fields of Durham and Yorkshire, of Lancashire and North Wales, appear from the dip and strike of the strata to be even now united though their junction is concealed by the covering of poikilitic sandstone.

Northern Coal District.

1. *Coal Field of Northumberland and Durham.*

This celebrated coal field extends from the Coquet to the Tees, occupying, according to Mr. Buddle, an area of 700 square miles, within which the coal strata may be traced continuously. From the Coquet to Shields it is bounded on the east by the sea, but south of that point the surface is covered by a triangular area of magnesian limestone, the apex of which is on the northern bank of the Tyne, while the base extends from Hartlepool on the east, to Pierce Bridge on the west.

It was long maintained by the coal viewers of the north of England, that no coal of workable quality was to be found beneath this cover of magnesian limestone; but in 1821, Colonel Braddyl was persuaded by the late William Smith, in opposition to the opinions of practical men, to sink through it in search of coal, and the result has been the great South Hetton Colliery, and other valuable works.

The rise of the strata is towards the west, as shown in the valleys of the Tyne and Wear, which make a complete section of all the beds above the millstone grit; but there is every probability that the Northumberland coal field is in reality a synclinal trough, the eastern half of which is beneath the German Ocean, for at South Shields the beds rise towards the sea. The aggregate thickness of all the strata, including coal and "rock measures," is about 1620 feet, varying, however, in different parts. The total thickness of the coal seams varies from forty-five to sixty feet in about twenty-five seams, from a few inches to two yards thick, but seldom more than five seams of workable thickness, and often not more than one or two coexist in the same locality.

The most important beds are the "High Main" and the "Low Main," the first six feet, the second between six and seven feet thick. Between these, distant from each other about sixty fathoms, is the "Bensham," exceeding three feet, and the "Yard Coal," whose thickness is implied in its name. There are seven beds below the Low Main, but of inferior quality. The largest is the "Wickham Street," six feet, the lowest, the "Brockwell," three feet. The coal is in general bituminous, but with considerable variations. There is very little ironstone in this district. Iron pyrites is very abundant, both crystallized and disseminated through the coal. Calcareous spar is also blended with it, and deteriorates its quality, rendering it less bituminous.

It is difficult to identify the different sandstones and shales alternating with the coal at distant localities. The best defined sandstones are the "Grindstone," the "Seventy Fathom," and the "Main Post." The first supplies excellent grindstones, and a good building material; the two latter lie below it, a considerable thickness of argillaceous strata intervening. The Main Post is the most continuous, and always accompanies the main coal. The earthy strata included in the coal are called "bands." The most remarkable is the Heworth Band, which at first is a mere parting, but finally, in its range to the N. E., swells out to the thickness of eighteen fathoms. The wide denudations of the Tyne and Wear have destroyed an immense quantity of the most valuable beds of coal, but this destruction has been in some degree compensated by their complete exposure of all the contents of the coal field, by the facilities offered for the discovery and working of many of the seams in the infancy of the art of mining, and by the aid afforded even now to their cheap drainage by means of adits. Much coal is likewise destroyed, and much expense incurred in the working, by reason of the numerous dislocations of the strata by subterranean movements. The largest of the fissures occasioned by these movements are called "dikes," the less considerable "troubles," "slips," and "hitches." They are sometimes filled with sandstone and clay. Like the denudations of the valleys of the Tyne and Wear, they afford some compensation for the destruction of coal occasioned by them, and for the impediments they generally throw in the way of the workings. When filled with clay they dam up numerous springs, and cause them to find vent on the surface, and those faults which depress the strata retain valuable seams within the coal fields, which would otherwise crop out and be lost. The most remarkable of these dislocations is the Ninety Fathom Dike, so called because the beds on the north of it are thrown down to that extent below those on the southern side. It varies in width from a few inches to twenty-two yards, and is filled with indurated sandstone. The basaltic dikes of this district do not always alter the levels of the strata on either side of them, but they invariably deteriorate the quality of the coal, converting it into coke, and frequently cause the seam to *nip*, or diminish in thickness, in their vicinity. Irruptions of water, accumulated in abandoned works, or in some cases from the vicinity of the sea, occasion a lamentable loss of life in the collieries of this district; but their greatest scourge is the fire damp. This is the miner's name for carburetted hydrogen, which is disengaged in great quantities from some of the most valuable beds of coal, particularly the Low Main. The pitmen frequently open with their picks crevices called "blowers," which emit as much as 700 hogsheads of this gas in a minute, and continue in activity for many months, and when, from the want of a sufficient current of air circulating through the works to carry off this gas as fast as it is given out, the atmosphere becomes charged with it to the explosive point, it ignites on coming in contact with flame, and carries destruction among the workmen, not only from the violence of the blast, but from the effects of the "after damp," or "stythe," a mixture of carbonic and azotic gases resulting from the combustion of carburetted hydrogen in atmospheric air.

To prevent these fatal consequences no expense is spared by the coal owners, and the energies of the superintendents, aided by all the resources of science, are kept constantly on the alert, in watching the state of the air courses and regulating the ventilation. Large furnaces are kept burning at the bottom of the upcast shafts, to quicken the circulation, and in some cases powerful air pumps, worked by steam-engines, have been employed to abstract the noxious gas from the workings.

But the most valuable gift which science has bestowed on those employed in the collieries is the safety lamp, the discovery of which would alone have been sufficient to immortalize its illustrious inventor. Provided with his "Davy" the collier may now fearlessly venture into an explosive atmosphere, and if it does not afford perfect immunity from danger, there is no doubt that when used with proper precaution it greatly diminishes the risks to which he is exposed.

Produce and Consumption of Coal. The produce of this coal field is enormous. Besides the quantity consumed within the district, about five millions of tons are annually shipped from the ports of the Tyne, Wear, and Tees, for the supply of the metropolis, and of the eastern and southern coasts as far as Plymouth.

The great and rapidly increasing consumption of coal, arising from the increase of population, and the extended application of the power of steam—a power as yet only in its infancy—renders the probable duration of the supply of our coal fields a question of no slight interest. Various attempts have been made at solving this question, with how little success may be gathered from the discordant results obtained by those who have from time to time undertaken the investigation. Dr. Thomson estimated that the Durham coal field would support an annual consumption of two millions of tons for 1000 years. Dr. Buckland has reduced the period of its duration to 400 years, and Mr. Baily to 200, while some of the coal owners, who were examined before the House of Commons in 1830, extended it to 1727 years. If there is one person better qualified than another to form an accurate estimate on the subject, it is Mr. Buddle, the eminent coal-viewer, who has had the superintendence of most of the collieries of this district for nearly half a century, and in reply to a question addressed to him at the meeting of the British Association, he declared the calculations necessary to insure even an approach to accuracy to be of so laborious a nature, that he had hitherto shrunk from the undertaking.

In these calculations other elements are required besides the area of the coal field, the total thickness of all the seams of coal, and an assumed annual consumption. Much of the coal is inaccessible by reason of natural impediments; much is rendered unavailable by the want of system in the mode of working, which arises from the intermixture of property and the clashing of private interests: much, from the inferiority of the coal and the thinness of the seams, will remain unwrought, until the enhanced price occasioned by a diminished supply shall allow it to be profitably worked.

On the whole, we may conclude that, however vast the stores of this valuable mineral with which Great Britain has been blessed, they are by no means inexhaustible, and that as the more valuable beds are worked out, the increased cost of production will cause a gradual rise of price, perhaps at no very distant day; it therefore becomes a point of great national importance that all unnecessary waste should be prevented.

The destruction of the small coal, by burning it in large heaps, at the pit's mouth, has frequently been the subject of severe and just animadversion. The practice originated in fiscal regulations, which enacted, till recently, that coal should be sold in London, by measure, and not by weight. This waste has in some degree diminished, since the abrogation of that law, but it still goes on to a lamentable extent; nearly one-third of the entire produce of this coal field being annually thus destroyed, or left in the mines, to avoid the expense of raising it to the surface. To remedy this abuse, it has been proposed to compel the coal owners, by law, to sell the coal without screening it. A process has however recently been invented, by which this refuse may be formed into cakes, better adapted for the use of steam vessels than the large coal, because, among other reasons, they can be more conveniently stowed, and it is to be hoped that this discovery, by causing a demand for what is now of no value, will effectually prevent this waste, and supersede the necessity for legislative interference.

2. *Coal Field of South Yorkshire, Nottinghamshire, and Derbyshire.*

This is another extensive and valuable coal field, closely allied in its characters to that of Newcastle, and it is, perhaps, a re-emergence of the same strata from beneath the magnesian limestone. The strike of the strata being, as in that coal field, from north to south, their dip to the east, beneath the magnesian limestone, and their western outcrop against the rocks of the millstone grit which constitute the higher regions of the Penine chain.

The number of coal seams contained in it, has been estimated at thirty, varying from six inches to eleven feet, and constituting a total thickness of twenty-six yards, with numerous alternations of grits and argillaceous strata, some of them containing ironstone. The thickness of the entire series in Yorkshire exceeds 3000 feet.

The towns of Leeds, Halifax, Bradford, Huddersfield, Wakefield, Chesterfield, Sheffield, Nottingham, Pontefract, and Derby, are situated either upon, or closely adjoining to this coal field, which supplies fuel to the important manufactures carried on in the adjoining district, and, by means of inland navigation, to the counties lying southeast of Derbyshire.

3. *Coal Field of North Stafford.*

This, sometimes called the Pottery Coal Field, is a small detached district, whose greatest length is about fifteen miles, having Cheadle and Newcastle-under-Lyne on or near to its eastern and southern extremities, and Congleton on its northwestern edge. It has been ascertained to contain thirty-two beds of coal, from three to ten feet thick, which are found at various depths, from fifty to four hundred yards. The strata, which are subject to great dislocations, dip from the sides, towards the centre of the basin, with an inclination amounting on the eastern side to one in four, while on the western side it is still more steep. Some seams, only twenty inches thick, have been worked, but they are in general neglected if of less thickness than four feet.

4. *Manchester or South Lancashire Coal Field.*

This is an irregular crescent-shaped tract, the span of which is about forty miles. It extends from the borders of Derbyshire, into the southwestern portion of Lancashire, by Manchester, to Prescot, near Liverpool, having Macclesfield on the eastern or opposite horn of the crescent, and Colne near its northern termination, with the towns of Rochdale, Oldham, Bury, Bolton, Leigh, and Wigan, within its area. The strata may be described generally as dipping from the exterior, along with the millstone grit on which they rest, towards the inner edge of the crescent, beneath the poikilitic sandstone and magnesian conglomerate; but this general arrangement is interrupted by many local disturbances, which have not yet been accurately traced. This coal field is probably connected beneath the cover of poikilitic sandstone with the coal field of North Wales, and the estuary of the Dee, which dips towards it.

5. *The Coal Field of Whitehaven*

Forms a narrow band, skirting the northwestern flanks of the Cumbrian mountains from Egremont, a little south of Whitehaven to the banks of the Calder, where it is covered by the poikilitic sandstone of the Plain of Carlisle. A good section is displayed in the cliffs of St. Bees, where, the dip being to the south, the coal measures are seen covered by the magnesian limestone, and that again by the red marl. The largest seam of coal in the Whitehaven colliery, is nine feet thick. These works, which are very deep, some of the shafts exceeding a hundred fathoms, extend under the sea. The Workington mines were carried on in a similar situation, until an irruption of the sea in the year 1837, destroyed this valuable colliery, with much loss of life. This coal field supplies Dublin, and a large portion of the eastern coast of Ireland.

On the northern side of the great Tynedale fault, near Hartleyburn, and on the southwestern side of the Craven fault, at the base of Ingleborough, are two small coal fields, belonging to the series above the millstone grit, which have been thrown down by those dislocations to considerable depths below that portion of the same formation which caps the summits of the neighbouring hills. At Ingleborough, the difference of level amounts to 3000 feet.

II. CENTRAL COAL DISTRICT.

1. *The Coal Field of Ashby de la Zouch*

Is of an irregular figure, its greatest length, from N.W. to S.E., being about ten miles, its greatest breadth about eight. It is so much dislocated, that it may be regarded as two detached basins, rather than as a continuous whole. The strata, having rapid dips in various directions, are surrounded by horizontal beds of the poikilitic series, and approach on the east almost close to the slate rocks of Charnwood Forest. One of the coal beds has a thickness of from seventeen to twenty-one feet, arising probably from the union of several minor seams.

2. *The Warwickshire Coal Field,*

About sixteen miles long, extends from the villages of Wyken and Sow, three miles east of Coventry, to Polesworth and Wareston, five miles east of Tamworth. Its average breadth is about three miles. The strata dip to the W.S.W., the inclination on the eastern edge of the coal field being as much as 45°, but decreasing on the western side. The principal collieries are at Griff and Bedworth. In the former place, four beds of coal are worked, the largest of which is nine feet thick. At Bedworth, the two upper seams of the Griff Colliery, which were there separated by shale thirty-three yards thick, run together, and form one seam of the thickness of fifteen feet.

3. *South Staffordshire, or Dudley Coal Field.*

This coal field, so important for the extensive iron-works it maintains, is in length about twenty miles, from north to south, extending from near Stourbridge, over Cannock Chase to Beverton, near Badgeley, the greatest breadth between Walsall and Wolverhampton being about seven miles. Its superficies, from actual survey, is about sixty square miles. That portion of it south of Cannock Chase, eight miles long and four broad, is distinguished by the presence of a continuous bed of coal thirty feet thick, called the " Main," or " Ten-yard" coal, made up of thirteen different beds, some of them lying close together, others separated by thin bands or partings of shale. In Bloomfield Colliery, a phenomenon takes place, analogous to the splitting of the High Main of the Newcastle coal field, by the Heworth Band. The two upper beds of the ten-yard coal separate from the rest, and are distinguished by the name of " the Flying Reed," and the interval between them increases, till it amounts to twelve fathoms, four beds of shale and ironstone being interposed.

The number of coal seams in this field are eleven, with sixty-four of sandstone, clay, and shale. The ten-yard coal is about sixty fathoms below the surface at Dudley, cropping out to the north, and being lost at Bilston. None of the seams above it are considered worth working. The strata north of Bilston, and in Cannock Chase, are below the ten-yard coal, and are distinguished by the presence of valuable beds of ironstone. Several of these lower coal seams are of considerable thickness. These ironstone measures, emerging from beneath the main coal at the southern end of the district, occupy the tract between Halesowen and Stourbridge, containing the celebrated fire-clay; but some of the most valuable of the ironstones of the Wolverhampton or northern portion of the coal field, are there wanting.

Of the great mass contained in the ten-yard bed, it is calculated that one-third is left in the works as refuse, the pillars that support the roof occupy one-third, and one-third only is brought to the surface.

The carboniferous limestone, and the old red sandstone, are entirely wanting beneath this coal field, though traces of the former are observable in the neighbouring districts of Coalbrook Dale, and the Clee Hills. This circumstance is considered by Mr. Murchison as indicating the accumulation of the coal strata of Dudley, in a freshwater lake. They rest on the upper members of the Silurian system, the Ludlow rocks, and the Wenlock limestone. These appear on the eastern side of the field near Walsall, rising both in dome-shaped masses and rectilinear ridges ranging N.N.E., nearly parallel to the axis of the coal field, and also near Dudley, in a similar series of short and narrow anticlinal ridges, (Sedgeley Beacon, Hurst Hill, the Wren's Nest, and Dudley Castle Hill,) rising in the midst of the coal near the basaltic hills of Rowley. Against these Silurian rocks, the strata rest somewhat unconformably, and at a considerable elevation, dipping towards the centre of the basin. At Rowley, they partly rest on, partly pass under the basalt which chars the coal, and appears to have burst through it.

Many dikes and faults, chiefly filled with clay and sand, traverse the strata, and cause great variations in the same bed, in different parts of its course, and the whole carboniferous tract has been upcast, through a cover of new red sandstone, some of the lower members of which are dislocated conformably with the coal measures, proving that some of the greatest of these movements were subsequent to the deposit of the poikilitic series.

The extension of the coal measures beneath the new red sandstone, has been proved by the Earl of Dartmouth, who, after sinking 151 yards through the rock, reached the coal seams which overlie the ten-yard coal, throughout the Dudley portion of the coal field. This was at Christchurch, one mile beyond the superficial boundary of the field.

The coal of this district is non-bituminous, and burns faster than that of Newcastle, leaving a white ash. The iron furnaces of Dudley and Wolverhampton, and the manufactories of Birmingham, consume an immense quantity of it, and it is conveyed, by means of canals, to the adjoining counties as far south as Reading and Gloucester.

III. Western Coal District.

1. *Coal Field of North Wales.*

This forms a narrow belt between the slate mountains of the Cambrian chain and the sea, commencing at the western cape of the estuary of the Dee, and extending to a point a little north of Wrexham, south of which two detached tracts appear at Chirk and Oswestry; the first three, the second about five, miles long, with a breadth of about half a mile.

The beds of the Flintshire coal field dip beneath the Dee, at angles varying from 12° to 35°, and rise on the opposite side of the estuary, finally sinking beneath the poikilitic sandstone, under which they are probably prolonged till they reappear in the coal field of Lancashire.

At Bagillt three seams are worked, the thickest of which is seven feet, and the thinnest three.

Coal is worked at two points in the Isle of Anglesey, in that depression parallel to the Menai Straits which extends from Red Wharf Bay to the Malltraeth Estuary; but it is doubtful whether this coal field belongs to the series above the millstone grit, or is subordinate to the carboniferous limestone.

2. *Coal Field of Coalbrook Dale.*

This coal field is bounded on the east, by an undulating line, ranging by Lilleshall to Bridgnorth, on the northwest, by a line nearly coinciding with the main road from Lilleshall to Watling-street, near Wellington, and thence by the Wrekin. On the west the boundary is formed by the elevated ridges of Benthall and Wenlock, broken by the gorge of the Severn, and on the south-east by the road from Much Wenlock to Bridgnorth.

The coal measures consist of the usual alternations of shale and sandstone with coal, having an aggregate thickness of 250 yards in 135 beds. The average thickness of the coal seams is about three feet, varying in number at different pits from one to sixteen. The upper seams are thin, generally sulphurous, widely separated, and extremely irregular. The lower seams are nearer together, and more persistent. The shale contains layers of iron-stone. The strata of this coal field exhibit several alternations of beds, containing freshwater shells of the genera unio and cyclas, with others containing producta, spirifer, ammonites, and other genera decidedly marine; the fossils occurring chiefly in nodules of ironstone, but sometimes in sandstones and shales. In the upper part of the series is a bed of freshwater limestone.

Beneath the coal measures are slight developements of old red sandstone, argillaceous limestone, and shale, identified by their fossils with the carboniferous limestone; while the Silurian rocks on which they rest are exposed in the flanks of the Wrekin, and in the escarpments of Benthall and Wenlock Edge.

This coal field is much shattered by numerous and complicated faults, the largest of which tilt the strata in various directions. Those on the east and west bring the coal strata on a level with those of the poikilitic system, through which the whole coal field has been upheaved. Only the lower members of that system, clay, marl, sandstone, and calcareous conglomerate, are found in the immediate neighbourhood. They pass conformably into the coal measures below, and exhibit, according to Mr. Prestwich, some unconformity to the upper poikilitic strata.

3. *Plain of Shrewsbury.*

West of Coalbrook Dale there are some detached and much broken coal fields, the most important of which is a curvilinear zone extending from the northeast flank of the Brythin Hills to Wellbatch, near Shrewsbury, the carboniferous strata resting on the inclined edges of Silurian rocks, and dipping towards a common centre beneath the new red sandstone. Detached portions of the same zone occur at Sutton and Uppington, and they follow the sinuous outline of the northern flanks of the Longmynd and Caer Caradoc. Three thin beds of coal are for the most part observable. At Pitchford the whole carboniferous series is described by Mr. Murchison,* as represented by a bituminous shale of a few feet in thickness. The coal measures of this district contain, like those of Coalbrook Dale, a band of freshwater limestone, and pass up conformably into the base of the poikilitic sandstone.

4. *Clee Hills.*

The Brown Clee and the Titterstone Clee Hills, which rise a few miles south of Coalbrook Dale, afford several small coal fields, thrown up to considerable heights above the adjoining country of old red sandstone, more interesting from their geological relations to igneous rocks than from their economical importance.

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* Proceedings of Geological Society, vol. i. p. 472.

In the Brown Clee Hill the coal seams are thin, in the Titterstone Clee Hill the principal bed has a thickness of six feet. The base of the coal-bearing strata is hard sandstone, sometimes passing into a conglomerate, the equivalent of the millstone grit, between which and the old red sandstone is a thin zone of the carboniferous limestone. The coal measures are, for the most part, covered with basalt. In the Titterstone Clee Hill the dike through which it flowed may be clearly traced, and the coal strata are broken by a series of faults, upcast towards the points where the basalt found vent.

On the east of these hills, and between them and the Severn, is another small coal tract, about eight miles long, extending southwards from Billingsley to the borders of Shropshire and Worcestershire. Coal also occurs at Over Arley on the Severn, adjoining this tract on the west, and in two small patches at Pensex, near the foot of the Abberley Hills.

Southwestern Coal District.

1. *Coal Field of South Wales.*

This great coal field extends from Ponty Pool to St. Bride's Bay, a length of a hundred miles, its greatest breadth in the counties of Monmouth, Glamorgan, Caermarthen, and part of Brecon, being nearly twenty miles, while in Pembrokeshire it is not more than five. This elongated oval area forms a vast basin, or rather double basin, having an included anticlinal axis, the strata cropping out on the north and south, and being skirted all round the basin by a zone of carboniferous limestone, which emerges from beneath them. On the south the strata dip at an angle of 45°, on the north the inclination does not exceed 12°. This district is intersected by deep valleys, running north and south, and many of the beds of coal are worked by means of adits driven into the sides of the hills.

The beds of coal are twenty-three, having an aggregate thickness of ninety-five feet. Of this about seventy feet are composed of twelve beds, varying from three to nine feet, and the remaining twenty-five feet are composed of eleven beds, whose thickness varies from eight inches to three feet.

The southern side of the basin from Ponty Pool to Caermarthen Bay yields bituminous coal, the northeastern side coking coal, and the northwestern stone coal and culm. Great faults, ranging in general from north to south, traverse the strata, and alter their relative levels on each side from forty to a hundred fathoms; but these dislocations seldom show themselves on the surface. The faults are generally filled with clay. One near Swansea, many fathoms wide is filled with fragments of the broken strata. The lower part of the series in the neighbourhood of Merthyr, is distinguished by the prevalence of shale, the upper part by the predominance of grit of a loose texture, abounding with specks of coal. This rock, known locally by the name of "pennant," divides the upper and lower parts of the coal series, and constitutes the summits of all the principal mountains in the interior of the basin. The lower part of the series contains numerous strata of coal and sixteen beds of ironstone, richer than that of Staffordshire. The most valuable bed of iron is below the lower coal. This basin supplies the greater part of Wales, the whole of Cornwall, and the western side of Devonshire, and maintains the iron furnaces of Merthyr, as well as the smelting works of Swansea, where nearly the whole of the copper ore of Cornwall, Wales, and Ireland, is reduced.

2. *Forest of Dean.*

An irregular basin, having Colford as a centre, the length from N.N.E. to S.S.W. being about ten miles. The coal beds are seventeen in number, giving a total thickness of thirty-seven feet. The dip of the strata is towards the centre of the basin. The exterior ridges of limestone and old red sandstone, prolonged across the Wye, form the mountainous tract between that river and the Usk.

3. *Coal Fields of Somersetshire and South Gloucestershire.*

These occupy an irregular triangular area, extending from near Iron Acton on the north, to Coalford at the base of the Mendip Hills on the south, nearly twenty-five miles, and from the Newton Collieries near Bath on the east, to those of Bedminster near Bristol on the west, about eleven miles, the course of the Avon nearly coinciding with this shorter line and dividing the coal field into two almost equal portions. The stratification, which has undergone much derangement, is subject to great local irregularities, the beds being sometimes vertical and even bent backwards into sharp and short flexures, so as to form within this area several smaller basins. The coal series is only denuded in a few places, as about Iron Acton, Brislington, Newton, the Vale of Pensford, near Clutton, and at Coalford. In other parts the coal is worked by means of shafts sunk through the overlying strata of new red sandstone, lias, and inferior oolite.

This cover of newer rocks, combined with the irregularities in the dip of the beds, renders it very difficult to trace the series of deposits in this coal field; but it is probable that there are between fifty and sixty seams of coal, some of them very thin, and none of them of more than a yard in thickness.

CHAPTER XII.

CARBONIFEROUS SYSTEM.—CONTINUED.

Carboniferous series in Ireland—large area occupied by carboniferous limestone—coal fields of Ireland—distribution of old red sandstone—carboniferous deposits of other parts of the world—France—Germany—South Russia—India—Australia—America.—Organic remains—prevalence of marine fossils in the carboniferous limestone—peculiar structure of the fishes of this era—four distinct fossil floras—character of the carboniferous vegetation—palms—coniferæ—ferns—sigallaria—lepidodendra—calamites—stigmariæ.—Climate of the Carboniferous era.—Origin of the rocks of this system—igneous rocks and mineral veins—evidence that the veins are more recent than the strata traversed by them—their productiveness in different rocks.—Springs.

CARBONIFEROUS SERIES IN IRELAND.

IRELAND may be described as a great sheet of carboniferous limestone, spread over the plains and broad undulations of the interior, supported at the four corners by masses of primary rocks and patches of old red sandstone, and partially covered by carbonaceous deposits. Coal has been found in seventeen counties, but not in considerable quantity, nor in general of good quality. Mr. Griffith divides them into four coal districts, named after the four provinces of Ireland. The Leinster and Munster districts afford stone coal; the Connaught and Ulster districts, bituminous coal. The Leinster district is situated in the counties of Kilkenny, Queen's county, and Carlow, extending for a short distance into Tipperary. This is the principal carbonaceous district. It is divided into three coal fields, separated by carboniferous limestone, which envelopes and passes under the whole. The coal of Kilkenny is nearly pure carbon.

The Munster district covers a considerable portion of the counties of Cork, Limerick, and Kerry, and is the most extensive in Ireland.

The Munster district covers a considerable portion of the counties of Cork, Limerick, and Kerry, and is the most extensive in Ireland. The strike of the strata is east and west, as in the basin of South Wales, and the dip to the south, at an angle of 45°. Coal has been wrought in the neighbourhood of Canturk for nearly a century; and the Dromagh colliery has yielded

25,000 tons of culm per annum, applicable to the purposes of lime burning. In this colliery, four beds have been worked. The uppermost, three feet thick, is stone coal, not sulphurous; the two lower beds are culmiferous deposits, one of which, called the "bulk bed," occurs in immense masses or "bulks," in which the ordinary directions of roof and seat are lost.

Lough Allen, the source of the Shannon, is the centre of the Connaught coal district. Coal and iron have been worked at Arigna, and the iron was of good quality, but the badness of the roof was a serious impediment to the profitable prosecution of the works.

The Ulster coal district commences near Dungannon, in the county of Tyrone, and extends southwards. The principal collieries are at Coal Island and Dungannon.

Bituminous coal has likewise been found in the neighbourhood of Belturbet in Cavan, and of Ballycastle in Antrim. The latter collieries are of very trifling importance, and are chiefly remarkable for some old workings discovered in them about a century ago, manifesting considerable mining skill, but of such high antiquity, that no tradition exists in the neighbourhood respecting the people by whom they were wrought.

Distribution of the Old Red Sandstone.

The principal districts of old red sandstone, are about Omagh and Enniskillen; on the southern side of Donegal Bay; on the northern side of Clew Bay; in the vicinity of Boyle and Longford; on the northwestern side of Lough Derg; about Killaoe and Limerick, surrounding the Keeper Mountains, and extending N.E. to Mount Mellick, in the Queen's county; south of Tipperary, surrounding the Gaultee Mountains, and in a narrow tortuous band, ranging by Waterford to Thomastown.

CARBONIFEROUS DEPOSITS OF OTHER PARTS OF THE WORLD.

Our notice of foreign localities, in which coal occurs, must be very brief; but brief as it is, it will show how extensively the carboniferous series is distributed. On the continent of Europe it extends from its central regions to the confines of the Arctic circle, the coal and lignite of Spain, Italy, and Greece, belonging to more modern epochs.

In France a small coal field occurs at Litry and Bayeaux, which appears related to the carboniferous deposits of Devonshire, and more extensive tracts are found between Anjers and Nantes. In the centre and south of France, in the valleys of the Loire, Allier, Creuse, Dordogne, Aveyron, and Ardeche, between ridges proceeding from the central primary group of the Cevennes, there are, according to Mr. Conybeare, some small coal basins, which rest immediately on those rocks. But the most important carboniferous district is the great coal field, of rather assemblage of coal fields, of Northern France and Belgium, which commences at Hardingham, near Boulogne, and extending beneath the chalk, reappears about Valenciennes; in the valleys of the Scheld and Meuse; and near Aix-la-Chapelle.

On the right bank of the Rhine, other coal fields occur near the confluence of that river with the Ruhr, between the Rhine and the Moselle, about Sarrebruck, and near Walmohr, on the banks of the Glave, extending to its junction with the Nave.

The carboniferous limestone of the defiles of the Sambre and the Meuse, imparts to the scenery picturesque features, closely resembling those of the Wye and the Avon. The millstone grit group, in which aluminous shales predominate, divides the coal from the limestone on the Meuse, and in Westphalia, and acquires a greater developement in its course eastward. The old red sandstone is represented by red conglomerates in Belgium, but does not occur in Westphalia.

An extensive coal tract ranges for many miles on the south-west and south of Hanover, between Osnabruck and Hildesheim.

On the east of the Hartz Mountains, near Ballenstadt and Neustadt, coal measures rest on grauwacke rocks, and are covered by the poikilitic formation, associated with porphyry. Coal is found in Saxony, in many places, on the northern flanks of the Erzegebirge, and is extensively worked near Zwickau and Dresden, resting on, and alternating with, porphyry, and other igneous rocks. It is said, that the coal formation occurs on the northern side of the primary chain of the Riesengebirge and Carpathian Mountains, and extends through Poland into Moldavia and Wallachia.

South of the Erzegebirge and Riesengebirge, in the basin of Bohemia, there is an extensive coal field, bounded on the south by the great slate district of Bohemia, in which forty beds of coal are said to be worked. Coal of good quality occurs in Southern Russia, near Koula, but the quantity is small, and the roof is so bad as to render it of little value. In Sweden, it is found at Helsinberg, near the entrance of the Baltic, and in the Island of Bornholm, where carbonaceous deposits are associated with rocks of all ages, from the strata of this system to those of the supercretaceous era.

Coal of indifferent quality is worked on the borders of the Persian Gulf, and in China. In India, good coal is found in abundance in Bundelcund, and in most parts of Cutch. The collieries of Burdwan, 130 miles from Calcutta, contain a seam three yards thick, have been worked about twenty years, and produce annually 15,000 tons.

Coal is also raised at Bhaugulpoor, on the Ganges, and at Merzipoor, on the Hooghly, forty miles from Calcutta. The coal of

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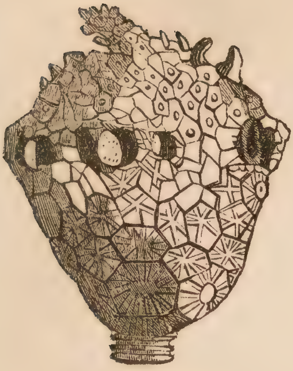

Pelvis of Actinocrinus 30-dactylus.

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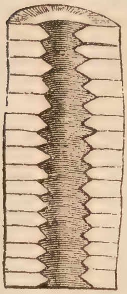

Section of part of the column of Actinocrinus 30-dactylus.

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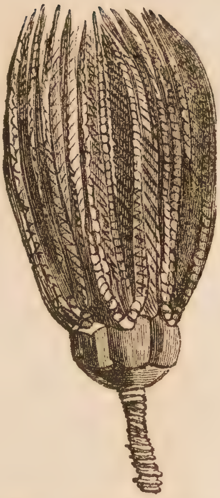

Pelvis of Platycrinus lævis.

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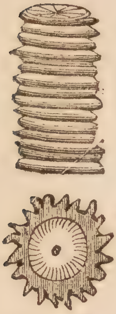

Column of Platycrinus lævis.

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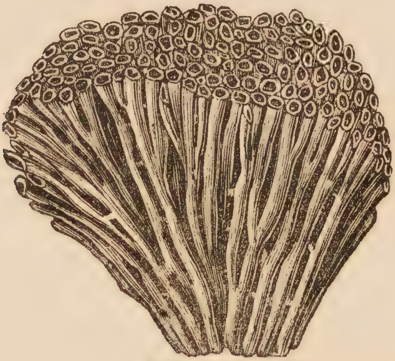

Syringipora ramulosa.

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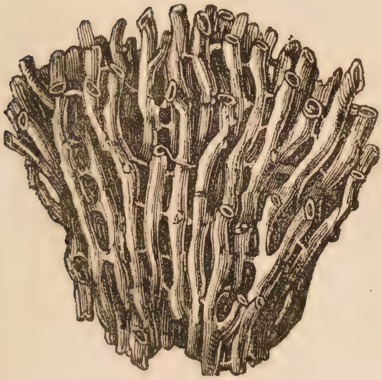

Syringipora cespitosa

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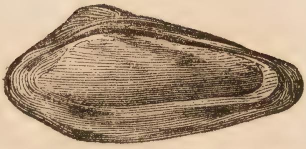

Unio acutus, (Ironstone of Bradford.)

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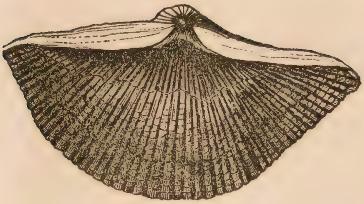
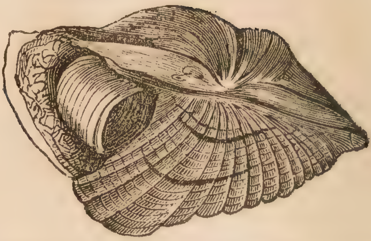


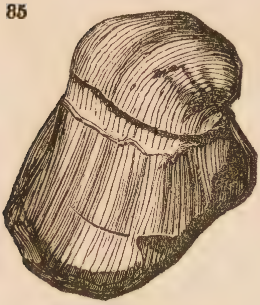
Spirifera attenuatus,
(Carboniferous Limestone.)

84



Spirifera trigonalis, (showing the spiral appendage.)
Carboniferous Limestone.)

85



Producta Martini,
(Carboniferous Limestone.)

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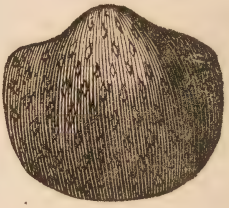
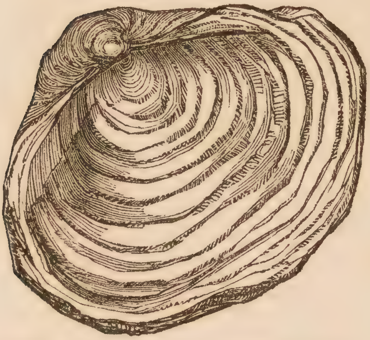


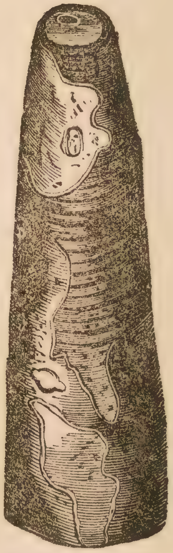
Producta scabricula,
Carboniferous Limestone
and Coal Strata.)

87



Producta punctata, (Carboniferous Limestone,)

88



Orthoceras
undatum.

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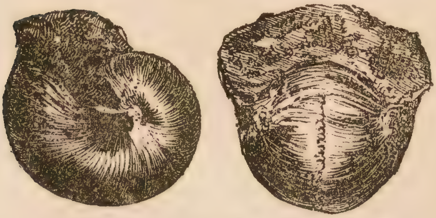

Bellerophon hiulcus, (Carboniferous Limestone.)

the Birman Empire is described as of good quality. Collieries are worked in Australia and in Van Diemen's Land.

North America contains extensive deposits of coal. The great coal field of Pictou, in Nova Scotia, covers an area of 200 square miles. The seams resemble those of Staffordshire, and one of them is said to be forty feet thick, though only the upper ten feet are considered worth working. There is also an extensive coal field, containing eight seams, which vary in thickness from one to four, though the coal is considered inferior to the last mentioned district; and numerous other parts of the province afford indications of coal.

At Cape Breton it occurs in abundance, and of good quality. The Sydney coal field has been estimated to contain an area of 120 square miles of valuable coal, in fourteen beds, from three to eleven feet thick.

In the United States are several extensive coal districts, that of Virginia, east of the Appalachian Mountains, which supplies the towns of Washington and Richmond, extends for forty miles, with a breadth of ten miles, surrounded by, and reposing on, primary rocks.

Beds of coal, interstratified with the limestone, sandstone, and shale of the great secondary formation west of the Appalachians, extend from the Ohio to the Tombigbee, in Alabama, the coal seams varying in thickness from a few inches to ten feet. Sandstone is the lowest member of the formation. At Wheeling, on the Ohio, and at Pittsburgh, there is a considerable consumption of coal for manufacturing purposes. West of the Mississippi, beds of ironstone are associated with the coal.

The southern parts of Chili, in South America, contain an extensive coal field.

Organic Remains.

The rocks of this system are extremely rich in organic remains, comprising zoophytes, molluscs, crustaceans, and fishes, of many genera and species, all the first, and nearly all the three latter, being marine; but neither reptiles, birds, nor mammalia, have yet been discovered in any rocks of this epoch. The plants, which occur chiefly in the coal formation, are almost wholly terrestrial; a few are supposed to have been aquatic. The zoophytes are almost, if not entirely, confined to the calcareous portions of the carboniferous limestone formation. They are stated by Professor Phillips to amount to 84 species, three of which are echinida, and the remainder polyparia and crinoidea, in nearly equal proportions. The last are a family now nearly extinct (76—79.) Most of the corals belong to extinct genera (80, 81.) Of 339 species of molluscs, 326 are derived from the carboniferous limestone, the remainder from the coal formation, in which occur the only species, ten in number, which can be considered as belonging to freshwater, or estuary genera (82.)

Among the conchifera (bivalves) of this epoch, the prevailing genera are spirifera, 43 species (83, 84;) producta, 38 species (85—87;) terebratula, 21 species. The first of these genera commenced with the Cambrian rocks, and became extinct in the lias; the second, commencing at the same epoch, expired in the poikilitic era, and the third continued through all the fossiliferous strata, and is represented by 15 living species. Of the cephalopoda,* the prevailing genera are orthoceras 28 (88,) bellerophon 23 (89,) nautilus 26, and ammonites 33, species. The first two are peculiar to the Cambrian, Silurian, and carboniferous systems. The genus nautilus is found in strata of all ages, being most abundant in rocks of the carboniferous era, while it is represented in the tertiary strata by 4, and in the present seas by 2 species. The genus ammonites, commencing with 17 species in the fossiliferous strata below the carboniferous, attained its greatest developement (164 species) in the oolitic system, and terminated with the cretaceous group (goniatites, 90.)† Of crustaceans the family of trilobites, so numerous and varied in the Silurian strata, ceased with the carboniferous era, while the genera palinurus, astacus, pagurus, and cancer, of more modern epochs, are unknown in it.

Peculiar Structure of Fishes of this System.

The fishes of the carboniferous system are found chiefly in Caithness and Forfarshire, in the old red sandstone, and at Burdie House, near Edinburgh; at Leeds, Bradford, and Manchester, in the coal formation. They belonged to the placoid and ganoid orders of Agassiz, which prevailed exclusively till the cretaceous epoch. These distinctions are founded on the form and composition of the scaly covering, which will be explained hereafter, when treating of the introduction of the two new orders of ctenoidians and cycloidians during that period. The fishes of the carboniferous system are nearly all distinguished by a peculiarity of structure in the tail, called heterocercal (93,) that is, it is divided into two unequal lobes, as in the shark and sturgeon, instead of terminating into two equal lobes, as in the salmon, or in a single rounded lobe, as in the wrasse; and the vertebral column is continued into the upper lobe of the tail, which is the largest. This structure becomes more rare after the deposition

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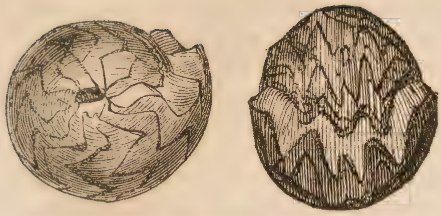
* Molluscs having the organs of progression arranged around the head, as the arms of the sepia or cuttle-fish. Their shells are in general divided into separate chambers, as in the nautilus. The extinct genus bellerophon is unchambered, like the modern argonauta or paper nautilus.

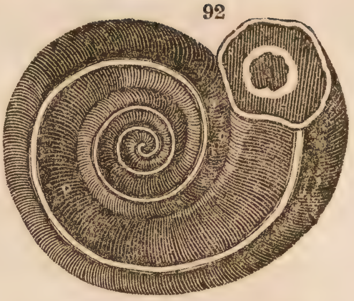
† Goniatites, a section of ammonites, peculiar to the Silurian and carboniferous strata.

90



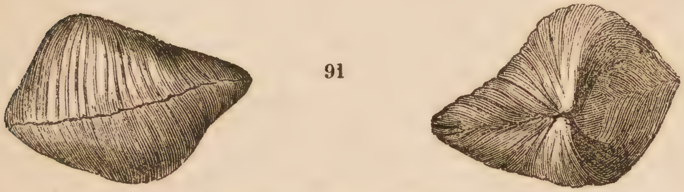
Goniatites sphericus, (Carboniferous Limestone.)

92



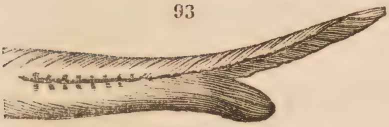
Euomphilus pentagonalis, (Carboniferous Limestone.)

91



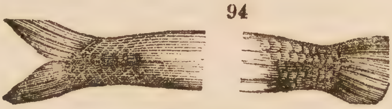
Cardium Hibernicum, (Carboniferous Limestone.)

93



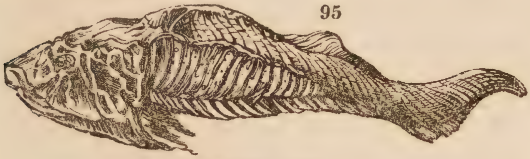
Heterocercal.

94



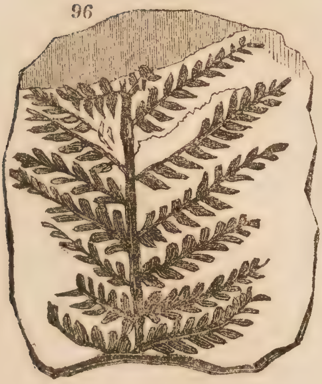
Homocercal.

95



Cephalaspis Lyelli.

96



Pecopteris Bucklandi.

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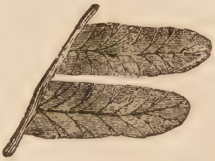
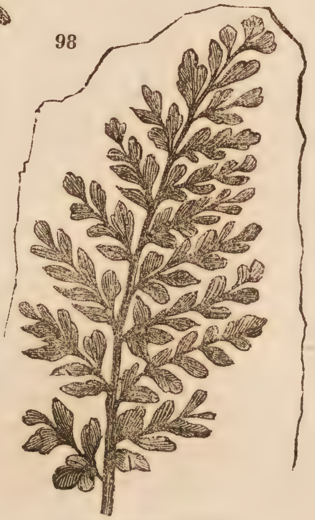


Pecopteris Bucklandi, (Magnified leaf.)

98



Sphenopteris Hibberti.

of the magnesian limestone. The homocercal structure or tail (94,) terminating in two equal lobes, the vertebral column not prolonged into either of them, prevails among living fishes.

The largest fishes of the carboniferous system belonged to a predaceous family, named by Agassiz sauroid. They were not, however, intermediate between reptiles and fishes, but were true fishes, in which the close sutures of the skull, the character of the covering, the conical teeth, striated longitudinally, and the articulation of the spinous processes with the vertebræ, presented analogies to the organization of saurians. The only living representatives of these sauroid fishes are the genera lepidosteus and polypterus, containing between them 7 species. The former inhabits the rivers of North America, the latter is found in the Nile, and the rivers of Senegal. In these living genera the air-bladder approaches the character of lungs, being bifid and cellular, and they have a glottis in the throat, thus exhibiting further analogies to the structure of saurians. The old red sandstone of Scotland has afforded fishes of a singular genus, named cephalaspis (95,) from the buckler which covers the head. Fragments of these shields had been mistaken for parts of the shell of a tortoise, and the general appearance of entire specimens had caused them to be considered trilobites of the genus asaphus, until their true nature was pointed out byAgassiz.

Four distinct Fossil Floras.

The fossiliferous strata have been divided by botanists into four epochs, distinguished by peculiar groups of vegetable remains. The first terminates with the carboniferous system; the second belongs to the poikilitic system; the third includes the oolitic and cretaceous deposits; the fourth is the tertiary epoch. The floras of the carboniferous and the tertiary systems are the best known, and have afforded the greatest number of species. The first exhibits the greatest deviation from existing types, while in the tertiary strata the forms of the dicotyledonous plants, which now prevail upon the earth, first become at all abundant.

Vegetation of the Carboniferous Era.

The fossil plants of this system are principally confined to the coal formation. The seams of coal are composed of their accumulated remains, and they are also found dispersed through the shales and sandstones of the coal formation, of the millstone grit, and of the limestone, when divided by arenaceous and argillaceous alternations, but are rare in the old red sandstone, and still more so in the undivided limestone. In the shale they are better preserved than in the coal. The species at present discoverd amount to 300, consisting of 20 equisetaceæ, 100 filices, or ferns, 60 lycopodiaceæ, 10 phanerogamous monocotyledons, 10 coniferæ, 50 cactaceæ, and 50 indeterminate.

Palms.

Palms are among the most rare of the coal plants. No trunks have been found, but the impressions of the leaves are sometimes met with. Their fruit (trigonicarpum) is more abundant, occurring in clusters of contiguous but separate nuts, which appear to have lain in the water till, the soft integument having rotted, they fell asunder and were buried in the mud.

Coniferæ.

Wood retaining its texture exists in considerable quantities in a mineralized state in the coal beds, and when reduced to thin slices and examined under a high magnifying power, is found in general to have a structure analogous to that of existing coniferæ. Some have been considered identical with it and referable to the genus pinus and araucaria.

Ferns.

These are the most abundant plants of the coal shales, and are those which have the greatest resemblance to existing types.

From the absence of the fructification, the genera (pecopteris, neuropteris, sphenopteris, &c.) into which they have been divided by the cultivators of fossil botany, are characterized by the branching of the fronds and the disposition of their nervures or veins (96—101).

Sigillariæ.

Large stems are occasionally found accompanying these leaves of ferns. They are destitute of leaves, from six inches to five feet in diameter, and sometimes forty or fifty feet long. To these the name of Sigillaria has been given. In the shale, where they lie parallel to the strata, they are generally squeezed flat; in the sandstone, where they are erect or inclined to the stratification, the bark is converted into coal, surrounding columns of sandstone which contain fragments of leaves and branches of ferns. These stems must, therefore, have been hollow (102). They have been supposed to be tree-ferns. That division of sigillariæ to which Professor Lindley has given the name of caulopteris (103), is distinguished by having their exterior marked with oblong scars of considerable size, much wider than the spaces which separate them, and having their surface interrupted irregularly by projecting

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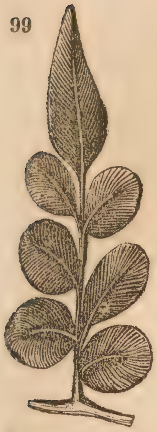
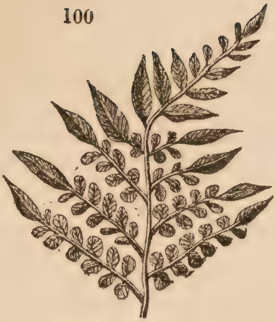


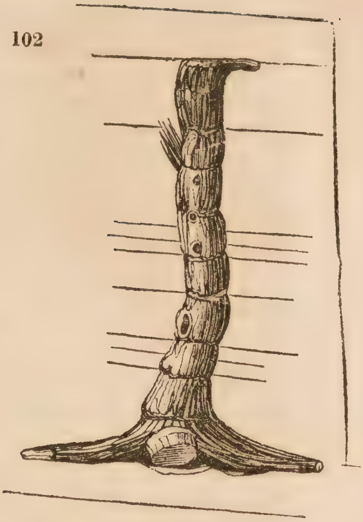
Neuropteris loshii
(Magnified leaf.)

100



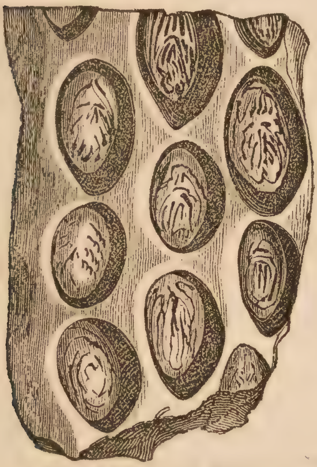
Neuropteris loshii.

102



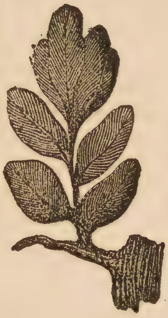
Trunk of Sigillaria pachyderma.

103



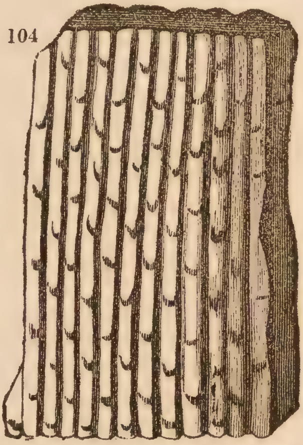
Bark of Caulopteris Phillipsi.

101



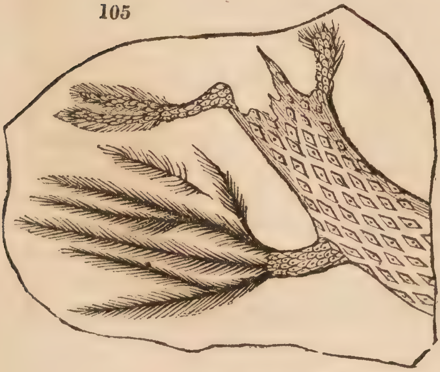
Sphenopteris Hibberti,
(Magnified leaf.)

104



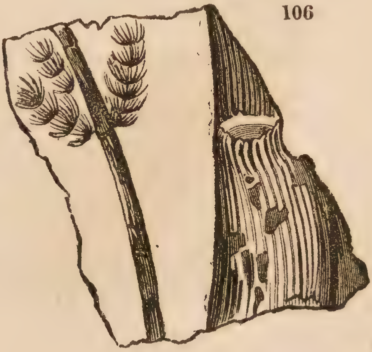
Bark of Sigillaria pachyderma.

105



Lepidodendron selaginoides.

106



Calamites nodosus.

points. These appearances arise from the manner in which the woody parts of the leaves were connected with the stem, and there can be little doubt that the trunks on which these impressions are found to belong arborescent ferns, the existing genera of which are marked with similar scars, produced by the fall of the fronds; but the inference cannot be considered equally well established with respect to that more numerous section of sigillariæ in which the stem is marked by flutings with a single row of scars between them (104). It is more than probable that they were cacti, to which they have also been compared.

Lepidodendra,

Which are very common in the coal measures, are considered analogous to lycopodia, or club mosses. They occur as impressions in the shale, covered with lozenge-shaped spaces, disposed in a spiral manner, or by scale-like leaves, the fall of which is supposed to have produced these spaces (105). Some of them are no larger than existing lycopodia; others have been found with stems forty or fifty feet long, and four feet in diameter. Existing lycopodia, of which there are 200 species, abound in the torrid zone, and these attain their greatest size, but that does not exceed a height of about four feet. Some botanists have supposed the fossil lepidodendra not to have been lycopodia, but coniferous trees analogous to the araucaria, or Norfolk Island pine, a conjecture which acquires probability from the discovery, already mentioned, that some of the specimens of fossil coniferous wood are nearly identical with the wood of that genus.

Calamites

Usually occur as short-jointed, cylindrical, or compressed fragments, which have been hollow, and are sometimes filled with the substance by which they have been mineralized (106.) The exterior is marked with longitudinal striæ, and sometimes partially covered with a bituminous coating, the remains of bark. One of the extremities tapers to a point, which is supposed to be the summit; the other, which terminates abruptly, is considered the root end.

They were referred by Brongniart to the tribe of equisetaceæ, or horse-tails, the species of which are most abundant in the temperate zone, and arrive at their greatest magnitude under the tropics, where they attain a height of two or three feet, and a diameter of about an inch; whereas calamites are frequently six or seven inches in diameter, and a few specimens have been found double that size.

The presence of a cortical covering is a proof that they were not even of the same natural class as the equisetaceæ, and botanists now consider them as belonging to a race of plants entirely extinct.

Stigmariæ

Are among the most abundant plants of the coal formation. They are usually found as fragments of an irregularly compressed roundish form, apparently portions of branches, the surface of which is covered with tubercles spirally arranged and having small cavities in their centres. From these cavities long riband-shaped appendages have been traced for many feet, penetrating the surrounding sandstone and shale in all directions. These fragments, sections of which exhibit an internal structure different from that of any known tree, have been recently proved by Mr. Hutton to have been derived from large dome-shaped bodies, from the margin of which proceed horizontal branches, varying in number from nine to fifteen, spreading downwards, and usually divided into two arms. They are generally broken, the longest at about four feet from the stem, but when perfect were probably much longer. It has been conjectured by Dr. Buckland that these stigmariæ were succulent aquatics, which trailed in swamps or floated in still or shallow water.*

Climate of the Carboniferous Epoch.

Such then was the vegetation of the carboniferous era. Abounding to an astonishing degree in individuals, it presents but little variety. A few palms and coniferæ, an immense quantity of ferns and lycopodiaceæ, constituting a third of the entire flora, are those plants which approach most nearly to existing tribes. Calamites, sigillariæ, and stigmariæ, with a few others, are those in which no analogy to our present races of plants can be satisfactorily traced. It contains no lichens nor fungi, no grasses, none of those herbs and shrubs so numerous at present on the earth, and no traces of endogenous trees. From this it has been inferred that the earth in its earlier ages was clothed with a less varied vegetation than now; and since palms, ferns, and lycopodiaceæ, are the prevailing plants of the torrid zone, and the two latter delight in moisture as well as heat, the preponderance of these in the flora of the carboniferous era has been appealed to as a proof that a damp and hot climate like that of the tropics prevailed during that era over the northern regions of Europe and America.

Calamites and sigillariæ being regarded as gigantic equisetæ and tree-ferns, the same inference has been drawn from their abundance in the coal strata. Both conclusions have been controverted, and it has been contended that this want of variety in the fossil flora might arise, not so much from the limited diversity existing in the vegetation of this ancient epoch, as from the greater destructibility of the absent tribes by long immersion in water; and in support of this argument an experiment has been adduced which was made by Professor Lindley. Having kept 177 plants immersed in water for two years, among which were species of all the orders which occur in the carboniferous strata, and species representing the remaining orders and families at present existing, he found that in that time all had entirely decayed except the ferns, palms, lycodiaceæ, and coniferæ. The fructification of the ferns had also disappeared, while the nervures and the leaves remained, conditions, it will be remembered, under which they are found in the coal measures.

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* Bridgewater Treatise.

On the other hand, it is improbable that the coal plants remained suspended in water for a year or two. They were most likely rapidly enveloped in the sediment, carried down by the rivers which floated them into bays and estuaries, and the destruction of the fructification of the ferns may have taken place after they were imbedded in the sand and mud. Neither is there any reason for supposing that the plants found in the tertiary strata were deposited under different circumstances, as regards immersion in water, from those of the carboniferous era, and yet in these more recent strata we have abundance of the wood of dicotyledonous plants and impressions of their leaves, while the proportion of ferns is small. If, therefore, at the time the carboniferous strata were deposited, dicotyledons bore the same proportion to ferns and lycopodiaceæ which they bore during the tertiary era, they must have left some traces of their forms in the shale and sandstone, as they have in those more modern deposits.

Again, as regards climate, admitting calamites and sigillariæ not to have been gigantic equisetæ, and putting them out of the question, as plants in which we cannot trace sufficient analogy to existing forms to warrant us in founding inferences as to climate upon them; yet the abundance of the fern tribe, the presence of undoubted arborescent ferns (caulopteris), and of palms, the character of the coniferæ, their analogy to the quasitropical genus araucaria, and the absence of those coniferæ, which now abound in the forests of cold regions, justify the conclusion that the plants of the coal series grew under a high temperature, on land diversified with low islands, arid plains, and mountain slopes. On the first, according to existing analogies, the ferns and lycopodiæ would flourish, the second would support the palms and cacti, and the third would be clothed with forests of coniferæ.

The high state of preservation in which the plants are found, with the exception, perhaps, of those of Melville Island, precludes the supposition of their having been drifted from any great distance by oceanic currents, like the tropical fruits and wood sometimes cast upon the coasts of Ireland and Norway, and it becomes difficult to avoid the conclusion that, during the formation of the carboniferous strata, the earth was exempt from local peculiarities of climate, but was subject to a general superficial heat prevailing at the same time over the latitudes of the north of Europe, Greenland, North America, and Australia. The same conclusion may be drawn from the consideration of the marine remains, —lamelliferous corals, crinoidea, and large cephalopoda, which are so abundant in the carboniferous limestone, in every part of the world where it has yet been found, are all characteristic of the seas of hot climates.

Origin of the Carboniferous Strata.

Having thus satisfied ourselves as to the climate of the carboniferous era, by a comparison of its fossils with their living analogues, we may next inquire by what means the terrestrial remains became interstratified with deposits containing marine exuviæ. Were the seams of coal, as contended by Brongniart and De Luc, of the nature of peat-bogs, formed on the land from the decay or destruction of forests, or did they result from the waste of those forests, rolled down by great rivers like the Mississippi and other American waters, which bear annually to the sea immense masses of trees, covering its bed near their embouchures with sediment and drift timber, arranged in alternating beds like the coal, shales, and sandstones of the carboniferous strata?

The second hypothesis appears preferable, as a general explanation, though the first may be applicable to particular cases. Of these cases, one of the most remarkable is that discovered by Mr. Hawkshaw in an excavation for the Manchester and Bolton railway, of five trees, in a vertical position with respect to the plane of the bed in which they stand, which dips at an angle of about 15°. The roots, large and strong, and spreading nearly four feet in circumference, are imbedded in a soft shale, immediately beneath a thin seam of coal. Beneath this coal, and at the base of one tree, more than a bushel of hard clay nodules was found, each inclosing one cone of *Lepidostrobus variabilis.* The bark of the trees was converted into coal from one quarter to three quarters of an inch thick. The interior of the trunks was filled with shale. The largest was 15½ feet in circumference at the base, 7½ feet at the top, and its height 11 feet. These trees have not been removed from the position in which they were found, and have been covered by a shed to protect them from the weather.*

The manner in which thin partings, such as the Heworth

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* Proceedings of Geological Society, vol. iii. p. 140.

Band and the Flying Reed, in the midst of the larger coal seams, expand, in the space of a few miles, into beds, many feet or even fathoms in thickness, is analogous to the deposits in the deltas of rivers, and furnishes one strong argument against the accumulation of the coal strata upon the land. Another is found in the numerous alternations of marine strata with the seams of coal; since, in order to explain these, we should require from twenty to sixty depressions of the land, and as many re-elevations of it, in order to allow the supposed peat-bogs to be covered by deposits, containing marine remains; and of these repeated alternations and depressions, the coal strata furnish no independent evidence. The frequent occurrence of the trunks of sigillariæ, in positions either perpendicular to the planes of stratification, or much inclined to them, has been appealed to in favour of the theory of Brongniart and De Luc; but there is rarely any proof of their being actually rooted on the place of their growth. The roots, when they have roots attached, are not in general all in the same stratum, and that of a different composition from the rest of the deposit, like the dirt bed of the Isle of Portland in the oolitic formation, but they occur at different levels; and sandstone, precisely the same as that in which the upper parts of the trunks are imbedded, envelopes the base. In fact, these upright and oblique stems offer analogies to the snags and sawyers so dangerous to vessels navigating the American rivers; and thus tend to confirm the hypothesis they are adduced to invalidate. Those rivers frequently undermine portions of their banks, together with the trees growing on them; and some of them sinking with their roots downwards, become fixed in the mud and sand in an oblique position. In confirmation of this view, we may cite the case of a group of sigillariæ, discovered by Mr. Buddle, in one of the Newcastle collieries, and of which he exhibited a drawing in the geological section of the British Association at Newcastle. In that group some of the trunks were nearly vertical, others were horizontal. The former had roots attached, the latter had not. The trunks of sigillariæ are, however, sometimes found in an upright position without roots,—a circumstance equally difficult of explanation under either hypothesis.

Supposing, then, that the plants of the coal measures were floated down by rivers, and deposited in the sea, the minor alternations of strata, containing marine and terrestrial exuviæ, will be best explained by the occasional prevalence of fresh water in bays and estuaries during periodical inundations; but when we find large masses of calcareous rock, containing exclusively marine shells and beds of coral, interstratified with coal, we must have recourse to those movements of the bed of the sea, of which we shall find conclusive evidence in more recent formations.

The excessive luxuriance of the vegetation of this epoch is a remarkable fact, which M. Brongniart has endeavoured to explain by supposing the atmosphere to have contained more carbonic acid than at present; and the conjecture is opposed to no chemical or physical law. It is uncertain whether the proportion of carbonic acid in the atmosphere is constant even now; were all the carbon in the coal converted into carbonic acid, and were the whole of that gas which enters into the combination of the carboniferous limestone* set at liberty, it must add considerably to the quantity contained in the atmosphere; carbonic acid is favourable to the growth of vegetables, and prejudicial to the life of warm-blooded animals; and during the period of this rank and luxuriant vegetation, we have no proof of the existence of a single animal breathing air by means of lungs.

Igneous Rocks of the Carboniferous Epoch.

Igneous rocks are extensively associated with the deposits of the carboniferous series, both in overlying masses, in stratiform beds, alternating with the sedimentary strata, and in dikes which have pierced through them. The prevalent minerals in these rocks are hornblende and augite, and their varieties; felspar porphyry being much more rare than in the Cambrian and Silurian systems.

The exact epoch when this igneous matter was ejected is not easily determined. When occuring in stratiform masses between beds of carboniferous limestone, like the whin-sill of the north of England and the toadstones of Derbyshire, it must have flowed as currents of submarine lava, contemporaneous with the formation of the limestone. Of overlying masses, all that can be determined is, that they are more recent than the rocks which they cover,—how much more recent cannot be ascertained; and the same remark applies to dikes, except when they trasverse certain strata, but do not penetrate others, like the Quarrington dike in the county of Durham, which cuts the coal but not the superincumbent magnesian limestone. Yet, even in such cases, the conclusion that the dike is older than the overlying rock is not always safe, for the igneous matter may have been ejected subsequently to the formation of the superior stratum, which accidental circumstances may have prevented it from penetrating. In England, dikes traversing deposits more recent than those of the carboniferous system are rare. In Ireland basaltic rocks have overflowed a great area of chalk. In Sky, Mull, and others of the Hebrides, they cover rocks of the age of the lias. Trap rocks of every variety are found associated with the great coal field of the Forth and Clyde. The Sidlaw Hills, north of the Frith of Tay, the Ochill and the Campsie Hills, in their range from its southern shores, by Perth and Stirling to Dunbarton, and in their expansion between Greenock, Ardrossan, and Kilmarnock, with the Haugshaw and Pentland Hills, are principally composed of these rocks; besides detached masses, some of them of considerable size, which are found about Montrose and Arbroath, near Cupar and Kinghorn, in Fifeshire, at Dunbar and Tantallon, on the opposite shores of the Forth, near Linlithgow, in various parts of Ayrshire, and in the Isle of Arran. That island is celebrated for the number of its dikes, and the variety of their composition,—basalt, greenstone, pitchstone, trachytic porphyry, claystone, and claystone porphyry. In all these localities they pierce or cover the coal, or the old red sandstone, but for the reasons before mentioned they may have been produced by many repetitions of igneous outbursts, some of which may have been contemporaneous with those which, in the Hebrides and Ireland, took place after the deposition of the lias and the chalk.

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* Sixteen thousand cubic feet to the cubic yard of limestone. De La Beche, Researches in Theoretical Geology.

In England, the principal masses of igneous rocks connected with the carboniferous deposits, are the porphyry of the Cheviots, the stratiform greenstone and basalt of the whin-sill of the north of England, and the toadstone of Derbyshire. The whin-sill may be traced from the sea coast north of Alnwick to the South Tyne, and thence along the western face of the Penine chain nearly to Brough and down the Tees to Middleton.

The coal fields of Durham and Northumberland abound with basaltic dikes, while those of Yorkshire, Derbyshire, and Lancashire are free from them. Igneous rocks appear again in the coal fields of Staffordshire, Shropshire, and Warwickshire. A basaltic dike occurs in Birchill Colliery, near Walsall. The hill of Rowley, near Dudley, and the Titterstone Clee Hill, are capped by masses of basalt. Mr. Bakewell, many years since, described the latter as connected with a great dike, and pointed out its effects in charring the coal; and Mr. Murchison has since confirmed his description. Trap occurs in protruded bosses among the carboniferous strata of Coalbrook Dale, and in masses, apparently interstratified with the coal at Griffe, in Warwickshire. In some of these localities the igneous rocks have effected those changes in the sedimentary strata near the point of contact, which have been described as produced among the Silurian rocks by the same agency, hardening shales and sandstones and converting them into flinty slate and jasper, charring coal, and at Cumnock, in Ayrshire, changing it into plumbago, rendering limestone crystalline, and in the cases already noticed in Anglesey and Teesdale producing garnets in the shale. There are, however, many instances in which no change has been effected in the aqueous strata, and this has probably arisen from diversity in the circumstances under which the trap was ejected, and from the varying composition of the sedimentary rocks, which rendered them more or less susceptible of the action of heat.

Mineral Veins.

These are rarely found in Britain in the old red sandstone, if we except the rocks of Devon and Cornwall, which are referred to this era, or in the coal formation, but the carboniferous limestone is highly metalliferous in those parts which are in the vicinity of axes or centres of disturbance, like the mining districts of the Penine chain, of Derbyshire, Flintshire, and the Mendip Hills, while veins are comparatively rare in those tracts which, like the greater part of Ireland, have been little affected by dislocations. Lead, copper, and zinc, are the prevailing minerals, of which lead is the most abundant, full two-thirds of the produce of Britain being raised from this formation. The ores occur as the sulphuret, carbonate, and phosphate of lead; sulphuret, carbonate, and oxide of copper; sulphuret, carbonate, and oxide of zinc, associated with calcareous spar, fluor spar, arragonite, selenite, carbonate and sulphate of baryta, sulphate of strontian, crystals of quartz, and iron pyrites. It is a very rare circumstance for the same district, and still more rare for the same mine, to be rich in both lead and copper.

Red hæmatitic iron is extensively worked at Ulverstone, and other places in the north of England, where it occurs in beds subordinate to the carboniferous limestone associated with pearl spar and carbonate of iron.

Veins are more recent than the Strata they traverse.

The mining districts of the carboniferous series, where the phenomena of the veins are less complicated by the intersection of numerous sets of them, and where the stratification of the containing rock is more apparent than in Cornwall, furnish conclusive evidence against an opinion prevalent among the practical miners of that county, that all metallic veins are of one age and contemporaneous with the formation of the rocks in which they occur. A vein which traverses, as at Alston Moor, &c., a series of fossiliferous shales, grits, and limestones, successively deposited, must be more recent than the lower beds traversed by it, and the evidence of subsequent origin becomes complete when a string of metal, as is often the case, passes through a fossil shell or encrinite.

In the north of England the most prevalent veins are those having a direction nearly N. and S., or what are called the "cross-courses;" the richest are the "right veins," or those running E. and W., or rather a little N. of E. and S. of W. The cross-courses in most recent cases divide and dislocate the right veins, and are occasionally productive near the point of intersection. The veins are almost always accompanied by faults in the strata, and the plane of dislocation hades or dips so as to pass under the depressed portion, as in the annexed diagram, where A is the depressed or downcast portion of the strata, B the upcast portion, cc the plane of dislocation inclined to the perpendicular, so as to dip under the downcast side.

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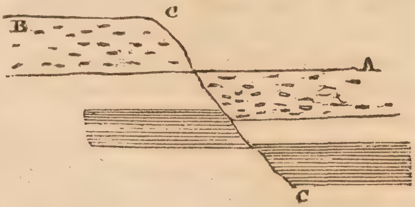

The hade, or dip, varies in strata of different quality, being most nearly vertical in solid rocks, such as limestone and hard grit, and least so in argillaceous strata.

The Productiveness of Veins in different Rocks.

Veins are also, in the north of England, more productive in the consolidated calcareous and siliceous beds, but nip or are contracted in the shale. Their productiveness also depends on the nature of rocks opposed to each other on the different sides or cheeks of a vein by displacement of the strata. Professor Phillips* gives the following formula as representing the favourable and unfavourable conditions dependent on this circumstance:

Side A.	Vein.	Side B.
Argillaceous.	Unproductive and narrow.	Argillaceous.
Argillaceous.	Partially contracted and poor.	Gritstone or limestone.
Gritstone.	Irregular in its produce.	Gritstone or limestone.
Limestone.	Most productive.	Limestone.

It was at one time supposed that the toadstone of Derbyshire cut off the metalliferous veins of the limestone strata, and was therefore of subsequent origin; but this is not invariably the case, though the veins in their passage through it are reduced in general to thin strings poor in ore. In some of the mines of Derbyshire they have been profitably worked in the toadstone, and the whinsill of Northumberland and Yorkshire is very productive in ore.

Springs.

The caverns, with which the carboniferous limestone abounds, are frequently the channels of subterranean rivers, conducted into them through fissures, which are very abundant, and which receive not only the water which falls from the atmosphere, but engulph many of those streams which, having their rise in other strata, flow over this. Hence the sides and summits of hills of undivided limestone are generally deficient in springs, which, however, break out with great violence at their base, particularly when the bed below is argillaceous. One of the most remarkable of these is the celebrated well of St. Winifred, at Holywell, in Flintshire, which discharges eighty-four hogsheads of water in a minute, and turns no less than eleven mills in the distance of a mile from its source.

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* Geology of Yorkshire, vol. ii., p. 38.

All the hot springs of England (Buxton, Matlock, Bristol, Taafe's Well) are situated on the carboniferous limestone; that of Bath can scarcely be called an exception, for the lias through which it rises rests unconformably on that rock. They are all situated near great disruptions of the strata, and may be regarded as the effects of water which, having fallen from the atmosphere, has penetrated to great depths, and has been returned by hydrostatic pressure to the surface; and their heat is to be considered not as due to local causes peculiar to each locality, such as the decomposition of beds of pyrites, but as representing the temperature of the interior of the earth, modified by that of the cooler rocks through which it has passed in its rise.

CHAPTER XIV.

NEWER SECONDARY ROCKS.

Poikilitic System—general view of its characters in England, France, and Germany.—Details of the English series—new red sandstone formation—magnesian limestone.—German series—muschelkalk—zechstein—keuperschiefer—rothtodliegende.—Fossils, their scarcity except in the calcareous beds—connect carboniferous and oolitic systems—earliest remains of reptiles—saurians—footsteps of tortoises in Scotland—poikilitic flora—tracks of gigantic birds in America—of supposed marsupialia in Saxony and England.—Geographical distribution of the poikilitic rocks.—Rock salt—prevalent in this system, though not exclusively confined to it.—Gypsum.—Mineral veins rare in England—associated igneous rocks—remarkable alteration of a conglomerate of this series by the contact of trap.—Obscurity of the causes which produced the peculiar mineral characters of the poikilitic rocks.

POIKILITIC SYSTEM.

Synonyms. New Red Sandstone System; Saliferous System, English authors. 1. Red or Variegated Marls, English authors. *Keuper Marls* and *Muschelkalk*, German. *Marnes Irisées*, and *Calcaire Conchylien*, French. 2. New Red or Variegated Sandstone, English authors. *Bunter Sandstein*, German. *Grès Bigarré*, French. 3. Magnesian Limestone; Magnesian Conglomerate, English authors. *Zechstein* and *Keuperschiefer*, German. 4. Lower New Red Sandstone, English authors. *Rothtodliegende*, German. *Gres de Vosges*, French.

General View of the System in England, France, and Germany.

THE poikilitic* or new red sandstone system may be described as a great mass of arenaceous and argillaceous deposits, interposed between the coal measures and the lias, the characteristic colour of which is red, or red variegated with blue, yellowish green, white and buff, yielding gypsum and rock salt more abundantly than most other rocks, extremely poor in organic remains, but containing locally two subordinate calcareous formations, in which they are more abundant, and which are generally characterized by the presence of a considerable quantity of magnesia. To the lower calcareous formation belong the zechstein of Germany, and the magnesian limestone of England. The upper formation (muschelkalk) is wanting in the English series, the zechstein in the east and south of France, and both of them in Devonshire. The greatest developement of conglomerates is in the lower part of the series, of sandstones in the middle, and of marls in the upper part. The north of Germany, the southeast of France, and the northeast of England, afford the best types of the series. That of Germany is the most complete.

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* Ποικιλος, "variegated," from the mottled colour of some of its marls and sandstones.

The following is a synopsis of the whole:—

UPPER POIKILITIC FORMATIONS.

GERMANY.	FRANCE.	ENGLAND.
1. Keuper marls and grits.	1. Marnes irisées.	1. Variegated marls, and white and gray grits.
2. Muschelkalk.	2. Muschelkalk, or Calcaire coquillier.	2.
3. Bunter sandstein.	3. Grès bigarré.	3. Variegated sandstones.

LOWER POIKILITIC FORMATIONS.

4. Gypseous marls.	...	4. Gypseous marls.
Zechstein.	...	Magnesian limestone.
Keuperschiefer.	...	Marl slate.
5. Rothtodliegende.	5. Grès de Vosges.	5. Lower red sandstone.

BRITISH SERIES.

It is only in the north of England that the British series is complete. Professor Sedgwick, by whom it has been investigated, has established the following subdivisions:—

Red Sandstone Formation, 600 *feet thick at least.*

1. *Variegated Marls.* Red, blue, green, or white marls, containing gypsum generally, and rock salt and brine springs locally. Included in these marls are white and gray sandstones, chiefly found in Warwickshire, which are supposed to represent the keuper grits of Germany. Organic remains few and occurring only locally.

2. *Variegated Sandstone.* Red sandstone, occasionally white and mottled. Few or no organic remains. The lower part a red quartzose conglomerate in a base of red sandstone, without organic remains.

Magnesian Limestone Formation, 200 *to* 300 *feet thick.*

3. *The Laminated Limestones* of Knottingley and Doncaster, with layers of coloured marls. Few fossils.

4. *Gypseous Red Marl.* Red and coloured marls, containing a few organic remains.

5. *Magnesian Limestone.* Prevailing colour yellow, but subject to variations, sometimes purple; texture, various crystalline, com-

pact, laminated, earthy, concretionary, oolitic, and brecciated; sometimes devoid of magnesia. Organic remains locally abundant.

6. *Marl Slates.* Laminated, impure, calcareous rocks, of a soft, argillaceous, or sandy nature. Organic remains, ferns of several species, and fishes, chiefly of the genus palæoniscus.

7. *Lower Red Sandstone*, associated locally with incoherent sand and red micaceous shales. It sometimes resembles the grits of the coal measures on which it rests, and into which it occasionally passes. Organic remains, plants like those of the coal measures.

In Germany, where organic remains are abundant in the keuper and bunter sandstone, it would be difficult to separate them, but for the interpolation of the muschelkalk; and consequently in England, where the calcareous formation is wanting, and where fossils are so extremely rare, the identification of the variegated marls and sandstones of the upper part of the series with the keuper and bunter sandstein respectively, however convenient the subdivision may be, must be regarded as somewhat arbitrary, and requiring to be confirmed by the discovery of some equivalent of the muschelkalk, however feeble, which Mr. Murchison has recommended geologists to seek for between the upper red marls and the red sandstone.*

German Series.

Muschelkalk, Zechstein, Keuperschiefer, and Rothiodliegende.

For the type of the lower poikilitic formation, we must again look to Germany. A slaty marlstone has long been extensively worked in the country about Mansfield, in Thuringia, in Franconia, and the Hartz, for the sulphuret of copper which abounds in it. It consists of an upper or calcareous group, called the Zechstein, and a lower red quartzose sandstone and conglomerate, called by the miners Rothtodliegende, or "red dead lier," because the copper ceases, or "dies off," before it is reached. The zechstein, or calcareous portion, consists of marl, limestone, copper slate, and magnesian limestone, containing gypsum and rock salt. Its organic remains, which are numerous, correspond generically with those of the carboniferous series. The lower division or rothtodliegende, lying between the zechstein and the coal measures, is considered the equivalent of the lower new red sandstone of England, which occurs in a similar position.

In England the rocks of the poikilitic system are on the whole unconformable to the carboniferous rocks; but in Shropshire, Yorkshire, Cumberland, and Durham, Professor Sedgwick has observed an apparent passage of the base of the system into the coal formation. The more decided gradation of the two systems into each other in part of the north of Germany, has induced Hoffman to regard the old red sandstone, the carboniferous series, and the lowest member of the poikilitic system, as one great complex group, in which the carboniferous rocks are a mere local deposit. These views, however opposed by the general succession of these rocks in England, receive some countenance from the developement of the carboniferous series in Scotland, and particularly in the Isle of Arran, where it appears as a mere band of very inconsiderable thickness, in the midst of a great mass of red conglomerates, clays, and sandstones.

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* Proceedings of the Geological Society, vol. i., p. 327.

Organic Remains.

This system was once supposed to be entirely destitute of organic remains. In England, they are chiefly found north of the Trent and Dee. Plants have been met with in the red sandstone near Liverpool, and marine shells in the marls and calcareous bands near Manchester. But the greater portion of the organic remains are derived from the magnesian limestone of the eastern side of the island, which contains fishes, zoophytes, and molluscs, the lower red sandstone yielding many plants. The red sandstone of Scotland has produced footsteps of reptiles, but no organic remains. Fishes have been found in that of Ireland. Altogether, the fossils belonging to this system in Great Britain, are confined to about fifty species, and in Germany they do not exceed two hundred.

This System connects zoologically the Carboniferous and Oolitic Systems.

Few as they are, they are of great importance, as forming a connecting zoological link between the rocks of the carboniferous and oolitic systems. Viewing the poikilitic system in its zoological relations, we might class its lower part with the carboniferous, its upper with the oolitic system; but its peculiar mineral characters stamp it as one series of deposits due to peculiar causes, which continued in action over extensive areas while a great change in organic forms was in progress. With some genera of plants and shells, peculiar to itself, it contains others that are found in the coal series below, and in the oolites above. The genera cyathocrinus among crinoidea, producta among molluscs, and palæoniscus among fishes, belonging to the carboniferous and older rocks, terminate in the zechstein. The ancient genus orthoceras is not found in rocks of this epoch, nor do belemnites occur earlier than the oolitic deposits. On the other

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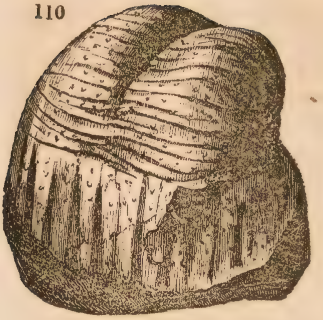
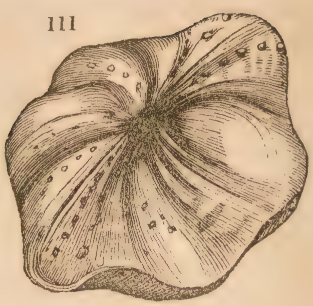


Producta calva,
(Magnesian Limestone.)

111



Producta horrida,
(Magnesian Limestone.)

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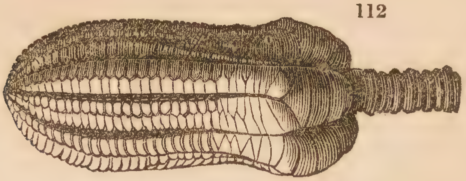

Encrinites moniliformis, (Muschelkalk.)

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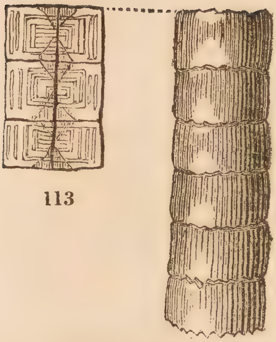

Stem of Encrinites moniliformis,
(Muschelkalk.)

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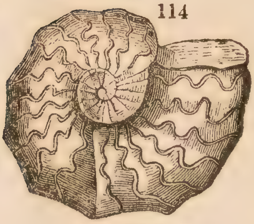

Ammonites nodosus,
(Muschelkalk.)

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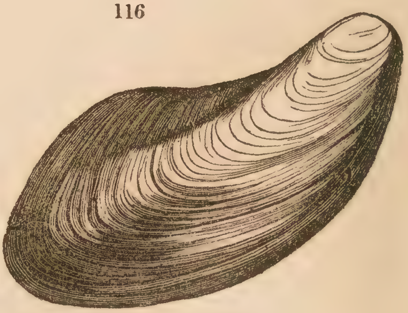
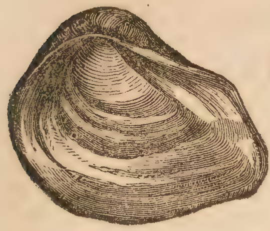


Avicula socialis,
(Muschelkalk.)

hand, the genus spirifera of the older strata continues into the lias, and the new genus trigonia, so characteristic of the oolitic epoch, commences in the upper part of the poikilitic series.

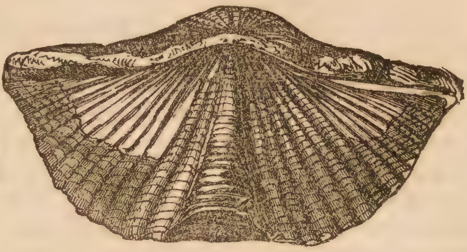
Figures are subjoined of some of the most remarkable shells of the magnesian limestone of England (108—111.)

108



Axinus obscurus.

109



Spirifera undulata.

Figures of Ammonites nodosus, Avicula socialis, and the beautiful lily encrinite (Encrinites moniliformis,) characteristic of the muschelkalk, are also given (112—116,) in order to assist the young geologist in the search which Mr. Murchison has recommended for some developement, however slight, of that rock, in England, between the variegated marls and sandstones, which constitute the upper part of the series.

Earliest remains of Reptiles.

The predaceous family of sauroid fishes are of a smaller size than in the older strata, and form but a fifth part of the entire number known in this system; but reptiles, which became so numerous during the oolitic epoch, begin now to make their appearance. Two genera of saurians (thecodontosaurus and palæosaurus,) allied to the iguana and monitor, have been found in the magnesian conglomerate, near Bristol, the lowest deposit in which reptiles have been found in Britain. On the continent, also, its equivalent, zechstein, is the oldest deposit which has yielded them, having produced protosaurus, a genus allied to the monitor. The newer muschelkalk affords phytosaurus, dracontosaurus, and three other extinct genera. The shell of a large species of turtle has been obtained from the muschelkalk near Luneville, and footsteps of terrestrial tortoises have been discovered on the upper surface of beds of sandstone belonging to this series, at Corncokle Muir, in Dumfriesshire.

Poikilitic Flora.

The remains of plants in the poikilitic series connect it in a similar manner with the systems above and below it. Its flora comprises coniferæ of the extinct genus voltzia, peculiar to this system, and several genera of ferns and cycadeæ. The genera lepidodendron and calamites, of the coal measures, terminate with the muschelkalk; the genera pterophyllum, and the gigantic equisetum columnare, of the lias, commence in the zechstein.

Footsteps of Birds in America.

On the new red sandstone of Connecticut, Professor Hitchcock has discovered impressions of the feet of birds, none of them web-footed, which he refers to seven species of grallatores, or waders. The largest are those of a bird which must have been twice the size of an ostrich, the length of the foot being fifteen inches, exclusive of the largest claw, which measured two inches. The footsteps occurred in regular succession, at intervals of four feet in some of the tracks, and of six feet in others, which was probably the longest step of this bird while running. The footsteps of another large bird, sixteen inches long, and more slender than the last, have a remarkable appendage, extending backwards from the heel, nearly nine inches, in addition to the length of foot above stated. This appendage appears to have been furnished with wiry feathers, or coarse bristles, and to have been intended to support the weight of a heavy animal, walking on a soft bottom, like a snowshoe, or the pieces of plank which the shooters of wild-fowl attach to their feet to prevent their sinking in the mud. The length of step increases in each track with the length of the foot, and is proportionably longer than the steps of any existing birds, from which it is inferred that the legs of these ancient birds were longer than in the modern grallæ. The steps, four feet asunder, are supposed to indicate a leg six feet long. The leg of the African ostrich is six feet long, that of the foot, ten inches.*

Footsteps ascribed to Marsupial Animals.

Every reader of *Robinson Crusoe*—and who is there that has not read it?—must remember the astonishment of that renowned navigator, when he discovered the prints of human feet on the shores of his desert island, the speedy realization of his forebodings by the bodily appearance of the cannibals following closely on the discovery of the footsteps, his splendid victories over them, savouring, it is true, somewhat of the marvellous, but supported by such minute returns of killed, wounded, and missing, on the part of the savages, as to leave no doubt of their authenticity, and, as a crowning achievement, the capture of that interesting personage, his man Friday. This fiction carries with it so much of the air of reality, as to have deceived many a reader into a belief in the actual occurrence of the events narrated, and among all the incidents which tend to produce the illusion, perhaps none is more effective than this of the footsteps, the importance of which as circumstantial evidence is known to all. Scarcely less great was the astonishment of geologists, when they discovered in the new red sandstone the tracks of some unknown quadruped, of whose existence the impression of his feet on the sands of that remote epoch are as yet the only evidence. The poikilitic system had long been the desert island of geology, deemed so utterly destitute of organic remains, that it was supposed to have been formed during a period of violent and universal convulsion, amidst which no living thing could exist on the face of the earth; and now, this system was found to contain locally, not only shells and plants, fishes and reptiles, tracks of land tortoises and of birds, but even of animals which appeared to belong to the marsupial order of mammalia.

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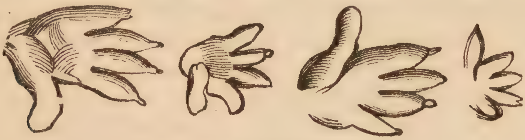
* Buckland's Bridgewater Treatise, vol. ii., p. 39.

These footsteps were first discovered at Hesseburg, near Hildburghausen, in Saxony, and from their resemblance to the form of the human hand, the animal by which they were impressed has received the provisional name of cheirotherium. The footsteps follow one another in pairs (117,) at intervals of fourteen inches between each pair, which consists of one large and one smaller print an inch and a half before it, each pair being in the same line. Both the large and smaller steps have the great toe alternately on the right and left side. Each has the print of five toes, the first or great toe being bent inwards like a thumb. The impressions of the hind foot are eight inches long, and five broad; those of the fore foot are four inches long, and three broad. The casts of the feet are in relief, on the lower surface of beds of sandstone, giving exact models of the toes and claws formed in a thin bed of clay over which the animal had passed, and which was sufficiently tenacious to retain the form of the foot until filled with sand, since converted into sandstone.

117



Footsteps of Cheirotherium.

It was conjectured by Dr. Kaup, the discoverer of these footsteps in Saxony, that they must have been impressed by some animal allied to the marsupialia, and Dr. Buckland has observed that, in the kangaroo, the first toe of the fore foot is set obliquely to the others, like a thumb, and that a great disproportion exists between the fore and hind feet. Should subsequent discoveries confirm this conjecture, this will be the oldest deposit in which traces of mammalia have been detected, the earliest remains of which, in secondary strata, confined to two or three jaws found in the calcareous oolitic slate of Stonesfield, are also referred to marsupialia.*

Footsteps precisely similar to those of Saxony have more recently been met with in considerable abundance in the quarries of new red sandstone, at Storeton Hill, near Liverpool. They occur on five consecutive beds of clay in the same quarry, and are accompanied by numerous smaller impressions, some of which are referred to the feet of saurians, and others to those of tortoises, multitudes of which appear to have traversed the beds of clay in every direction.

Further discoveries of footsteps of cheirotherium, and five or six small reptiles, have been made in the new red sandstone of Cheshire, Warwickshire, and Salop. Sir Philip Egerton has described one specimen found in Cheshire, in which the impressions of the foot were double the size of those of Hesseburg, and afforded other indications of having been made by a distinct species.†

In fact, so many of these tracks have recently been found in England, as to lead to the hope that bones or teeth will, ere, long, be brought to light—the latter, as the most indestructible, are the most likely to be met with, and the recent researches of Professor Owen, in odontography, have furnished means for determining the relations of the animal to which they belonged, since he has shown that the different orders and even genera are distinguished by peculiarities in the microscopic structure of their teeth, and by this unerring test he has been able to settle the disputed places of several extinct mammalia, reptiles, and fishes. We would therefore urge the young geologist, whose lot may be cast in the neighbourhood of the new red sandstone, to search diligently every quarry of that rock, within his reach, for bones and teeth—so may it be his good fortune to discover the mysterious cheirotherium, to

> Seek the den where *sand* tracks mark the way,
> And drag the struggling savage into day.

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* See Buckland's Bridgewater Treatise.

† Proceedings of the Geological Society, vol. iii., p. 12, 14, 15.

Impressions of Rain-drops.

The surface of beds of sandstone belonging to this, as well as other epochs, is frequently covered with ripple marks, such as we see on the surface of sandbanks, left dry by the recess of the tide, or covered by shallow water. These ripple marks are produced by currents of a certain velocity pushing forward the particles of sand, and their direction is always at right angles to that of the currents. The quarries, in Cheshire, which have yielded the footmarks of cheirotherium, also afford evidence of the fall of showers of rain on sandbanks, lying between the limits of high and low water. The entire surfaces of several partings of clay, in the same quarry, are covered with indentations precisely similar to those produced by rain under such circumstances, and the lower surface of the overlying sandstone exhibits casts in relief of these indentations.

" On the surface of one stratum, at Storeton," says Dr. Buckland,* " impressed with large footmarks of a cheirotherium, the depth of the holes formed by the rain-drops on different parts of the same footstep, has varied with the unequal amount of pressure on the clay and sand, by the salient cushions and retiring hollows of the creature's feet; and from the constancy of the phenomenon upon an entire series of footmarks in a long continuous track, we know that this rain fell after the animal had passed. The equable size of the casts of large drops that cover the entire surface of the slab, except in the parts impressed by the cushions of the feet, record the falling of a shower of heavy drops on the day on which this huge animal had marched along the ancient strand; hemispherical impressions of small drops upon another stratum, show it to have been exposed to only a gentle sprinkling of rain that fell during a calm.

" In one small slab of new red sandstone found by Dr. Ward, near Shrewsbury, we have a combination of proofs as to meteoric, hydrostatic, and locomotive phenomena, which occurred at a time incalculably remote in the atmosphere, the water and the movements of animals, and from which we infer, with the certainty of cumulative circumstantial evidence, the direction of the wind, the depth and course of the water, and the quarter to which the animals were passing; the latter is indicated by the direction of the footsteps which form their tracks; the size and curvature of the ripple-mark on the sand now converted into sandstone, show the depth and direction of the current; and the oblique impressions of the rain-drops register the point from which the wind was blowing, at or about the time when the animals were passing."

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* Anniversary Address; Proceedings of the Geological Society, vol. iii. p. 246.

Geographical Distribution of the Poikilitic Rocks.

British Isles. In tracing the geographical extent of the poikilitic system in the British Islands, we shall commence with England, where it is most largely developed, Scotland and Ireland affording only very slight traces of it.

We have already noticed the triangular area of magnesian limestone, covering the coal formation of the county of Durham, having its apex a little north of the Tyne, and extending westward from Harlepool on the sea-coast, to Pierce Bridge on the Tees. From this point the magnesian limestone ranges south in a narrow band between the carboniferous rocks on the west, and the new red sandstone formation on the east, by Ripon, Knaresborough, Tadcaster, Ferrybridge, Pontefract, and Mansfield, to Nottingham, constituting a chain of hills of moderate elevation, the highest points of which near its northern and southern terminations, rise to the height of about 600 feet above the sea. Parallel to this range of magnesian limestone, a broader tract of red sands and marls, varying from eight to twenty miles in width, extends from the mouth of the Tees by Thirsk and York, following the valleys of the Ouse and Trent to Nottingham. It then expands over a vast area about eighty miles long and fifty broad, occupying the whole centre of England in nearly horizontal strata, which surround the syenitic ridges of Charnwood Forest, and the upheaved coal strata of the counties of Liecester, Warwick, and Stafford.

This large central tract of the upper poikilitic formation, stretches northwest between the southern terminations of the Penine chain and the mountains of Wales, having on, or near to, its northeastern boundary the towns of Nottingham, Derby, Cheadle, Newcastle-under-Line, Congleton, Stockport, Manchester, Newton, and Liverpool. The southwestern boundary extends along the estuary of the Dee as far as Parkgate, and thence passes a little west of Chester by Wrexham, Ellesmere, Shrewsbury, Newport, Shifnal, Bridgnorth, and Worcester. From Worcester, a narrow band of the sandstones and marls runs down the valley of the Severn, abutting on the west against the Malvern Hills and the old red sandstone districts of South Wales, and bordering the western shores of the estuary of the Severn to the banks of the Usk.

On the eastern side of the estuary, the boundary of the new red sandstone formation becomes very intricate and irregular, from its surrounding small islands of the carboniferous and other older rocks, and from its being partially covered by detached portions of lias, and by alluvial deposits. From the same causes, its course through South Somersetshire and Devonshire is nearly as tortuous from the shores of Bridgewater Bay to the mouth of the

Exe, by Dunster, Watchet, Milverton, Taunton, Wellington, Tiverton, Collumpton, Crediton, Honiton, and Exeter, long tongues being thrown off westward among the older rocks, while on the east it is bordered by the lias of the oolitic, and the greensand of the cretaceous systems, which in South Devonshire is in immediate contact with it, without the intervention of any member of the oolitic series. On the southern coast it extends from Torbay on the west, to the neighbourhood of Sidmouth, where it is for a time concealed by the overlying greensand, but reappears about the mouth of the Axe, and runs up the valley of that river.

On the western side of the great Penine chain, we find that a gulf of the poikilitic sea entered between that range and the Cumbrian group. Marls and sandstones border both sides of the Solway Frith, and spread over the plain of Carlisle and the valley of the Eden. A narrow band of these rocks also skirts the Cumbrian mountains on the west, from a little north of Whitehaven to the peninsula of Furness. Coast sections, between Whitehaven and St. Bee's Head, exhibit in the descending order,—1. the variegated sandstone, St Bee's Head; 2. the lower gypseous marls; 3. the magnesian limestone, sometimes alternating with, sometimes resting on, the magnesian conglomerate; 4. the lower red sandstone, a reddish sandstone of considerable thickness, containing, though rarely, calamites, and sometimes appearing to graduate into the coal measures upon which it rests, though on the whole it is unconformable to them. Magnesian limestone does not appear in connexion with the red sandstone and marls of the great plain of Central England, except near Newton and Manchester, where it covers the coal field on the south, and in Shropshire and Worcestershire, where magnesian conglomerates underlie the red sandstone and marls, and are separated from the coal measures by the lower red sandstone, composed of sandstones, red shales, and marls, sometimes mottled with green. Magnesian conglomerates also rest immediately on the coal, in an unconformable position, near Bristol, and on the borders of the Severn. In these conglomerates fragments of the carboniferous limestone are united by a dolomitic paste. These, as well as the porphyritic conglomerates of South Devon, in which fragments and masses of porphyry are enveloped in an argillaceous cement, have been referred to the age of the todliegende, or lower red sandstone; but Professor Sedgwick contends that, in the southwestern parts of England, the lower part of the poikilitic system is entirely wanting, and that all these conglomerates belong to the magnesian limestone formation.

In North Wales, the vale of Clwyd is filled with the new red sandstone formation; and on the coast of Caernarvon Bay, for about five miles from the entrance of the Menai Straits, patches of red marl and porphyritic conglomerates are occasionally discernible beneath diluvial deposits. The same red marls and conglomerates border both sides of the Menai, for about three miles northeast of Caernarvon. This small tract is chiefly remarkable for affording one of those cases, of such rare occurrence in England, in which rocks of this age have been affected by igneous eruptions.

In Scotland, with the exception of the district, already mentioned, in Dumfriesshire, bordering the Solway Frith, all traces of new red sandstone, and those very slight, are confined to the western coast and the Hebrides. In Ireland, it occupies a more extensive area, stretching from Coleraine to Dungannon, and the southern extremity of Lough Neagh, passing under the basalt, and reappearing on the banks of the Lagan, whence it extends to the Belfast and Strangford Loughs. A narrow stripe also occurs on the eastern coast of Antrim, between Glenarm and Cushendon Bay.

Foreign Localities. On the continent of Europe large areas are occupied by deposits of this system, ramifying, as in England, though on a larger scale, among islands and promontories of older rocks, and overlying masses of more recent formations.

The red rocks of Devonshire, prolonged across the British Channel, are interposed between the slate rocks of Britany and the lias and oolite, by which they are almost concealed. The keuper, muschelkalk, and bunter sandstone, are largely developed in an extensive tract between the Ardennes and the Vosges. The keuper, in this district, contains some calcareous bands, but there is no zechstein between the bunter sandstein and the grès de Vosges, or rothliegende. The same rocks occur between the Vosges and the Schwartzwald, or Black Forest, from the eastern side of which they expand to the northward and eastward, constituting a large portion of the great area of secondary rocks between the primary and slate mountains of the Schwartwald, Rhingau, and Westerwald, on the west, and the Bohemerwald, Thuringerwald, and Hartz, on the east. The poikilitic rocks also pass round the Hartz, between Magdeburg and Brunswick. Within this area, the zechstein is found on the flanks of the Thuringerwald, in Hesse Cassel, on the southern and eastern side of the Hartz, between the Elster and the Saale, and around Waldeck. The muschelkalk is widely expanded from Waldshut, on the Rhine, to the Thuringerwald, and round the Hartz. A band of poikilitic marls, sandstones, and magnesian limestone, locally associated with rock salt and gypsum, occurs both on the north and south side of the Eastern Alps, between the primary rocks and the Alpine limestone, which is the equivalent of the oolitic series; and red marl, with rock salt and gypsum, underlies the same formation in the Jura, at the western termination of the Alps.

MINERAL PRODUCTS.

Rock Salt.

The prevalent and abundant association of rock salt with the poikilitic deposits of England and Germany, led to a very general belief that, wherever salt rocks occurred, they must belong to rocks of this geological epoch, to which were consequently assigned all mines of salt and brine springs, whether in Poland or Spain, European or Asiatic Russia, in Persia, Thibet, or Tartary, in Africa, and in North and South America; but recent investigations have corrected this hasty generalization, and have proved the existence of salts among rocks of all ages. It is probable that the celebrated salt works of Wieliczka, in Poland, belong to the tertiary series, and those of Cordova, in Spain, to the greensand. In the Austrain Alps, besides the saliferous deposits of the poikilitic era already mentioned, there is another, referred by Murchison and Sedgwick to the greensand. Bakewell places that of the Western Alps in the lias. In Wirtemburg it is found in the muschelkalk. In England our principal salt mines are in the upper marls, but several copious brine springs issue from the coal formation. The saliferous sandstone of the United States, west of the Alleghanies, appears to underlie the carboniferous rocks, and to be the equivalent of our old red sandstone; and a spring, containing a large proportion of salt, rises near Keswick, from the lower part of the slate rocks of Cumberland. The salt works of England are of high antiquity. Those of Droitwich, in Worcestershire, formed part of the public revenue during the Roman possession of Britain, and the brine springs of Nantwich were extensively worked by the Saxons.* The principal deposits of rock salt are at Northwich. Two beds are wrought, the uppermost of which is covered by about 110 feet of variegated marls, containing no trace of organic remains, and separated by rather more than thirty feet of similar marls from a lower bed, which has been sunk into to the depth of 108 feet without having been passed through. It is only in the central portions of these masses that the salt is sufficiently pure to be worked, the upper and lower parts being much contaminated with marl. The salt is divided into globular concretions, sections of which, with marl or impure marly salt between them, are exhibited on the walls and roof of the works. Sometimes the contact of the spheroids has produced hexagons like the horizontal sections of basaltic columns. Subordinate to these globular concretions the salt is cubically crystallized in pellucid masses, generally white, but sometimes tinged red by argillaceous sediment. The red varieties are frequently fibrous.

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* Conybeare and Phillips, Outlines of the Geology of England and Wales.

Gypsum

Occurs in various proportions in most of the clays associated with the rock salt of these works. This is a product of the argillaceous portions of the poikilitic system, which is more generally diffused than rock salt. Quarries of alabaster, or granular gypsum, are worked at Chellarton, and several other places in Derbyshire; the purer and whiter beds for ornamental purposes, and for the manufacture of plaster of Paris, the inferior kinds as a building stone. At Droitwich, two beds have been sunk through, forty and seventy-five feet thick. Fibrous gypsum, which is the more common form, occurs at Aust Passage on the Severn, associated with sulphate of strontian, and in several places near Bristol, associated with that mineral, and with sulphate of baryta. It also occurs at Nottingham, at Newbiggan in Cumberland, and various other localities.

Selenite occurs at Fairburn, near Ferrybridge, in Yorkshire; but this form of sulphate of lime is more common in other clays, particularly those of the oolitic system, than in rocks of this era.

The magnesian limestone usually contains 20 per cent. of magnesia. At Ferrybridge, and other places, it is burned for manure, but is considered injurious, unless applied in very moderate quantities, in which case it is highly beneficial. Some varieties, as at Leigh and Ardwick, are much esteemed for their property of setting under water.

Mineral Veins rare in England.

Though the keuperschiefer of Germany is so rich in copper, metallic veins are very rare in this system of rocks in England. Galena is found in marl slate, near North Shields, and has been worked successfully* in Yorkshire, in the thin-bedded limestone. Carbonate of copper occurs near Knaresborough and Tadcaster, and cobalt at Alderley Edge, in Cheshire; but with the exception above mentioned, these minerals are only found in strings too small to admit of their being profitably worked.

IGNEOUS ROCKS.

Irruptions of igneous rocks are equally rare. Pitchstone, claystone, and basalt, have pierced through rocks referred to this era in the Isle of Arran. Greenstone, filling the great Cockfield Dike, extends from Middleton, in Teesdale, to near Robin Hood's Bay, traversing successively all the series from the carboniferous limestone to the lias and oolite, inclusive. Mr. Murchison has discovered a trap dike, ranging E.N.E. from the Breiddin Hills in Shropshire, to Acton Reynolds and for fifteen miles beyond that point—thirty miles in all; elevating the strata into an anticlinal ridge, and indurating the sandstone, which is traversed by vertical fissures and strings of metallic substances. The same author has enumerated several places in the Thuringerwald, where the red sandstone is prismatized in contact with trappean or other igneous rocks.*

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* Proceedings of the Geological Society, vol. ii. p. 3.

Remarkable case of alteration by contact with trap. To these, we may add a case discovered by ourselves on the shores of the Menai, about two miles N.E. of Caernarvon, close to Llanfair church, where a red conglomerate of this series, composed chiefly of porphyritic fragments, in an argillaceous base, rests on a large plateau of augitic greenstone, which has sent off strings, from a few inches to four feet thick, into the conglomerate, though the mass of trap has not broken through nor disturbed it. At a hundred yards from this trappean rock, the conglomerate retains its red colour, but gradually changes through purple to black, as it approaches it, becoming more and more indurated, till a brecciated rock with a subcrystalline base is produced, having a close resemblance to some of the conglomerates of the Cambrian series of Snowdonia and Ireland; the red argillaceous base being converted into a dark and compact matrix, which contains crystals of vitreous felspar. At the same time, the felspathic matter of the pebbles has undergone a new crystalline arrangement, the more fusible varieties having disappeared, leaving cavities lined with crystals of felspar. This example is highly instructive, showing the mode in which the subcrystalline character of the rocks called "transition," might be produced in mechanical deposits of sandstone and clay. The masses of trappean rocks associated with the red porphyritic conglomerates of Devonshire, are considered by Mr. De la Beche to have been produced by volcanic ejectments, during the formation of those deposits: first, because between these porphyritic masses and the slate rocks, other conglomerates are sometimes found, containing no porphyritic detritus; secondly, because in the upper conglomerates, angular fragments of porphyry occur, often exceeding a ton in weight, which are not referrible to any rock *in situ* in the neighbourhood; and lastly, because some of the beds of sandstone among the arenaceous deposits appear to consist of volcanic sand, projected from a crater, and mixed with the sedimentary deposits then in progress.

Disturbances. From some of the beds of the lower new red sandstone, in the coal fields of South Staffordshire and Coalbrook

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* Proceedings of the Geological Society, vol. i. p. 326.

Dale, being thrown up at the same high angle as the carbonaceous strata, and conformable to them, Mr. Murchison has inferred, that the principal fractures around these coal fields took place after the deposit of a part, at least, of the poikilitic series.* A more decided instance of this occurs on the eastern side of the Vosges, where great precipices of the lower sandstone have strata of the upper part of the system spread out horizontally at their feet.

The fine-grained sandstones, and the upper argillaceous limestones, of this system, are both laminated, implying gradual deposit; the coarser sandstones occur in thicker beds; the marls are generally laminated; but where masses of gypsum occur, they frequently derange the lamination, and render it probable that they are due to segregation, subsequent to the formation of the strata.

Oblique Lamination.

In this, and other systems, we frequently meet with sandstones, in which the laminæ are not parallel to the general plane of stratification, as in *a a*, but oblique to it, or curved, as in *b c.*

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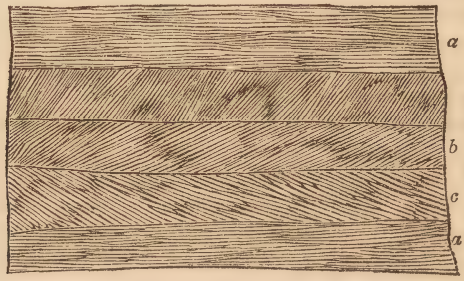

Parallel lamination may be regarded as the result of tranquil deposit, curved and oblique laminæ as the effects of conflicting currents varying in direction and velocity.

The magnesian limestones abound with veins and strings of carbonate of lime, and with sparry hollows, lined with crystals of the double carbonate of lime and magnesia. The limestones are also sometimes crystalline, and composed of the same double carbonate. They are also concretionary, having a small or large structure. The former, when regular, may be called oolitic. In the concretionary limestone of Sunderland, the globular masses have a radiated structure, and are frequently as large as cannon-balls, and the same concretion is sometimes common to two beds, which appears to prove that this structure was superinduced after the mechanical deposition of the beds.

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* Proceedings of the Geological Society, vol. ii. p. 195.

This structure is analogous to that of some of the tertiary lacustrine limestone of Auvergne, and to that of modern travertins, and pisolites, and may have resulted from submarine springs, holding their mingled elements in solution.

Origin of the peculiar Mineral Characters of this System, obscure.

The peculiar mineral characters of the rocks of the poikilitic era, their general red tinge, the prevalence of conglomerates in the lower part, the concretionary character of some of its limestones, the abundance of gypsum and of rock salt, appear to indicate peculiar physical conditions, existing during a considerable period, over extensive regions of the earth. The light of inductive reasoning may, perhaps, hereafter guide us to a discovery of the nature of those conditions, but at present we have not sufficient data to warrant us in attempting a solution of the question; and from conjectures, however inviting, it is most prudent to abstain. We may, however, from this point, take a review of the course of events marked by geological phenomena as having preceded the formation of this system of rocks, and we may cast our eyes forward over those which succeeded, tracing, as far as we are able, the relations of cause and effect subsisting between the various phenomena. In entering on this examination, we find that, from the commencement of the fossiliferous series, up to the period in the earth's history at which we are now arrived, four distinct epochs are clearly defined: two of repose, and two of disturbance. During each period of repose, a great succession of aqueous deposits appears to have been formed regularly and tranquilly, subject during their deposition to occasional local outbursts of igneous matter, like those of modern volcanic action, but not to any general fracture and elevation of the sedimentary strata evinced by the discordant position of different members of the series. The first tranquil epoch comprises the Cambrian and Silurian systems; the second includes all the carboniferous deposits. These two periods of repose are succeeded by two of the most general disruptions of the earth's crust of which we have any evidence, being observable in so many, and such widely distant localities, that they may almost be considered universal. Each of them is followed by a series of sedimentary rocks unconformable to the strata below, and consisting of conglomerates, marls, and sandstones, all coloured red; among which, organic remains and calcareous strata are rare, and only locally developed, the organic remains being chiefly confined to the calcareous beds, and to those in which the red tinge is wanting. During the period of repose which divided these two red deposits, there had been a great increase of organic life in the carboniferous system, and a great deposit of limestone, accompanied by dark-coloured argillaceous strata, like those of the slate series, but less indurated. The second series of red rocks is succeeded in a similar manner by great deposits of calcareous matter, (the oolites,) accompanied by a multitude of organic bodies, and alternating, as before, with dark-coloured clays. In the British Islands, the regular and tranquil deposit of sedimentary strata is nowhere broken by great movements of elevation, till the supra-cretaceous era; and we have, again, no general formation of red rocks, though some local deposits of rocks, resembling the poikilitic in colour, have been observed among the tertiary strata in other parts of Europe. We are thus led to connect an abundance of molluscs and corals with an extensive developement of calcareous rocks, their absence from those red systems where they are rare with the red colour, and that red tinge with extensive disruptions of the earth's crust.

The prevalence of conglomerates, immediately succeeding each fracture and elevation of the strata, indicates powerful currents produced in the sea by the new conditions of its bed. Their great mass indicates the violence of the watery action, and the extensive degradation of the newly raised land. The materials of which they are composed, generally referrible to the nearest upraised masses of rock, their unequal developement, their occasional absence, and the continuity then observable in the sequence of deposits, show that, however violent those disturbing forces, and however wide the areas over which they acted, they proceeded from a number of local centres, at a certain distance from which the effects of disturbance were only slightly felt, and sedimentary deposit and vital action proceeded in their regular course. Thus, in Great Britain, nothing can be more decided than the lines of demarcation marked by unconformable position, between the slate rocks and the carboniferous system, and between the latter and the poikilitic rocks; and yet, even within our own island, there are, as we have seen, spots where no such breach of continuity exists, but where they are in accordant position, and a gradual passage may be traced from the one into the other. The prevalence of conglomerates in the lower part of these red systems, and of sandstones and of marls in the upper part, shows a gradual diminution of the disturbing action, and a return from a very general state of disturbance to a very general state of repose.

There is this difference between the two periods: that the first is not marked by the extinction of large races of organic bodies, while the second is. The abundance of organic life during the carboniferous era, appears to have arisen rather from the extended developement, both as to species and individuals of genera already existing, than from the destruction of old, and the introduction of new types. The second period of disturbance connects zoologically the second and third period of repose. In its lower parts are found the expiring races, which had flourished during a long preceding epoch; its upper members exhibit the dawn of new tribes of plants and animals which were to be largely developed in the next superior system, and gradually in their turn to disappear and to be replaced by others.

We have before remarked that the series of tranquil sedimentary deposits, which succeeded the poikilitic system, is not in England affected by great fractures and tilting of the strata, till the tertiary era. We shall see, however, as we proceed, that it exhibits proofs of oscillations, by which deep oceans were converted into shallow estuaries, or even into dry land, again submerged, and again elevated; but these elevations and depressions appear to have been effected by a gradual intumescence and contraction of the crust, like that which we find to have taken place in recent times, and to be even now in progress, in the Scandinavian peninsula, and which, according to Mr. Darwin, is elevating and depressing alternate bands of the bed of the Pacific Ocean. To such movements, unaccompanied by violence, we have referred for an explanation of some of the alternations of strata containing marine and terrestrial remains in the carboniferous series.

But whence, it may be asked, arises the prevalent hue of the old and new red sandstones? In each of them, it is connected with extensive disruptions of the earth's crust, and with the absence of organic remains, to the preservation of which, or to the existence of animal life, it appears to have been unfavourable. In strata, likewise, of other epochs than the poikilitic, it appears to be connected with the presence of rock salt, gypsum, and limestone containing magnesia. Dr. Dalton found that, in the sandstone of Manchester, the red colour was a mere superficial crust, investing grains of clear quartz, and there is no doubt that in the marls and sandstones this red hue arises from the presence of peroxide of iron, as that of the greenish yellow and blue portions of the rock arises from iron in a lower state of oxidation. But whence, again, came all this oxide of iron? Mr. Lyell ascribes it to the abrasion of rocks of mica slate, or trap, containing it in great abundance. This explanation might be satisfactory with respect to a local red tinge, pervading the deposits of several epochs in the vicinity of such rocks, but appears inadequate to account for the periodical prevalence of that colour, and its general diffusion at particular epochs; and the rare occurrence of mica in the poikilitic sandstones is unfavourable to the hypothesis of their having been formed from the detritus of mica slate. Other geologists have suggested, that the prevalent red hue may have arisen from the general influence of volcanic eruptions on the sediment of the ocean. We would advance a step further, and inquire whether the oxide of iron, which forms the colouring matter, may not have been introduced into the waters of the sea in the form of a sulphate, flowing from submarine springs, during this extensive volcanic action. Dr. Forchammer, according to an unpublished suggestion, cited by Professor Phillips, has recourse to powerful submarine springs, charged with the mingled carbonate of lime and magnesia, for the origin of the magnesian limestone. The rock salt occurring in local masses in this formation, may have been produced, reasoning from existing analogies, either by the desiccation of the water of the sea by local heat; or it may have been derived from volcanic springs. The gypsum, lime, and silex, of the lacustrine strata of Auvergne, are ascribed by Mr. Lyell to cold and thermal springs, holding these different ingredients in solution during the successive convulsions attending the developement of volcanic agency; and the same author considers it probable that the zoophytic and shelly limestones, which constitute the coral reefs of the Indian ocean, were derived from submarine springs, which furnished lime to the waters of the sea, from which it was elaborated by organic agency; and may not sulphate of iron, which, as well as sulphuric acid, is found in the springs of volcanic regions, have been extensively diffused through the ocean, by the same means, during periods of intense disruptive action?

This idea was suggested by the copious yellow precipitate, produced in a mill-pool by the water flowing from the precipitation pits of the Parys Mine, after copper has been separated from a solution of its sulphate by metallic iron. As soon as the somtion of protosulphate of iron enters a stream of fresh water which feeds the pool, it acquires an additional dose of oxygen, and the yellow insoluble sulphate of the peroxide is deposited. The finer sediment of the central parts of the mill-pool is used as a yellow pigment, or converted into a red paint, by exposure to a low heat. The less pure parts, contaminated with sand and mud, are mixed with lime to produce a cement which sets under water, like those varieties of the magnesian limestone which contain much oxide of iron. Now, if springs holding the mingled carbonates of lime and magnesia in solution, entered this pool on one side, while proto-sulphate of iron, with an excess of sulphuric acid, flowed in at the other, we should have calcareo-magnesian deposits in one part, and yellow sediment in another, resembling, in colour, some of the yellow varieties of new red sandstone, and where the two solutions met, carbonate of lime would be decomposed, and sulphate of lime formed; and if the pool, instead of being filled with fresh water, were a shallow sea, the bed of which was subject to the action of subterranean heat, local deposits of chloride of sodium might take place, and the yellow colour of the argillaceous and sandy sediment would be changed to red.

We have experimentally formed red marl, resembling the poikilitic, by mixing clay, of the colour of the London clay, with a solution of sulphate of iron, exposing the mixture to the air, till it acquired a yellow colour, and then evaporating the liquid, and indurating the argillaceous matter, in a watch glass on a sand-bath placed over the flame of a lamp. It remains to be determined, whether, by mixing successive portions of argillaceous and sandy matter, with solutions of lime, magnesia, sulphate of iron, and chloride of sodium, and by the application of a moderate heat, red and mottled marls and sandstones may not be produced, containing the characteristic minerals of the poikilitic system. Some who may be disposed to admit that the oxide of iron was introduced in the form of a sulphate, will perhaps deny that it was poured out from the interior of the earth by submarine springs, and may prefer to derive it from the decomposition of iron pyrites contained in the shales of the coal measures, which suffered such extensive destruction during the movements which preceded the deposit of the poikilitic rocks.

CHAPTER XV.

General view of the Oolitic Group—northern and southern types of England—applicable to most of the north of Europe.—Table of subdivisions of the oolites in England—the lias—its subdivisions and mineral characters—range—great outlier in Shropshire—organic remains—peculiar structure of oolitic fishes—reptiles—ichthyosaurus and plesiosaurus—their sudden destruction and inhumation.—Inferior oolite—subdivisions—oolitic coal fields of Scarborough and Brora—organic remains—plants distinct from those of the carboniferous system—megalosaurus—pterodactyl—marsupialia.—Middle oolite—subdivisions—extent—characteristic fossils—Upper or Portland oolite—subdivisions—range—characteristic fossils—submerged forest of the dirt-bed—proofs of oscillations of level. Wealden group—subdivisions and range—fossils—fluviatile shells—plants—clathraria and endogenites—reptiles—iguanodon—hylœosaurus—birds—origin of this local deposit—absence of mammalian remains—Wealden coal field of the north of Germany—contemporaneous marine strata.—Geographical extent of the oolitic system.—Anomalous mixture of fossils in Southern Europe.—Disturbances and igneous rocks.

OOLITIC SYSTEM.

Synonyms. Oolitic formation, English authors. *Calcaire de Jura; Calcaire Jurasssique*, French. Lias, English authors. *Calcaire à Gryphites*, French. *Jurakalk*, German.

General View of the Oolitic Group.

This system of rocks derives its name from the concretionary character of some of its limestones, which are composed of small globular particles, resembling the eggs or roe of fishes.* It is extremely rich in organic remains, which form a group entirely distinct from those of the systems above and below it. Its subdivisions, at least over moderate areas, are better characterized by peculiar species than the rocks of any other part of the fossiliferous series. The study of these subdivisions, and of their fossil contents, led the celebrated William Smith to the discovery that England was divided into strata, succeeding one another in regular order, over great areas, with a dip towards the east, and that distant but contemporaneous groups of strata contained assemblages of plants and animals peculiar to themselves, each stratum having constituted successively the bed of the sea. The oolitic system, as Mr. Conybeare remarked, in his *Outlines of the Geology of England and Wales*, is susceptible of divisions by mineralogical characters into three natural groups, each consisting of argillaceous, arenaceous, and calcareous beds, succeeding one another in the same order, the argillaceous being in each case the lowest, supporting calcareous sand, which again is covered by numerous beds of oolitic limestone.

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* Ωον, "egg."

Northern and Southern Types. But though the rocks of the oolitic system maintain a certain general resemblance of mineral character in far distant localities, they are subject to considerable local variations, so that in the range of these rocks through England we have a northern and a southern type. That of the south is the most calcareous; that of the north is distinguished by the lower part of the group containing great masses of sandstone analogous to those of the coal formation, accompanied by thin beds of coal and layers of ironstone, while, at the same time, there is a diminution of calcareous matter. In the south-east of England, also, there is a local arenaceous deposit, which is wanting both in Yorkshire and the neighbourhood of Bath.

English Types applicable to most of the North of Europe. To the southern type of England belong the oolitic rocks of the greater part of France, and of a large portion of Europe. In Normandy they are scarcely distinguishable from those of the south of England, even to some of the minor subdivisions; but in the south of France, and in the Jura, from Geneva to Beyreuth, though analogous to the English series, the formations are less easily distinguishable. To the Yorkshire type are referrible the small patches of oolitic rocks which occur in Scotland and the Hebrides, and those of the northern parts of Westphalia. In Wirtemburg, a part of Franconia, and along the flanks of the Alps, from Switzerland to Vienna, the calcareous masses acquire a great developement, and the argillaceous members diminish, thus constituting a third type, in which it is difficult to recognise any formation, except the lias and oolite. These are represented in the Alps by dark-coloured schists and limestone, so compact that the organic remains are only discernible on a weathered surface, and hence they were, for a long time, referred to the transition or slate series.

The following table exhibits the different formations and subdivisions in the south of England:

Formations.	*Thickness.*	*Subdivisions.*	*Lithological characters and Fossils.*
	Yards.		
Wealden (Local).	300	Weald clays.	Blue clay, with beds of marlstone, and shelly limestone, and layers of ironstone. Freshwater shells.
		Hastings sands.	Gray, or ferruginous sand and sandstone. Land plants, bones and teeth of iguanodon.
		Purbeck beds.	Limestones, shales, and marls. Freshwater shells.
Upper Oolite.	130	Portland oolite.	Limestone, locally oolitic; some beds full of marine shells.
		Kimmeridge clay.	Clay, blue or bluish yellow, with selenite, and layers of bituminous shale. *Ostrea deltoidea*, in beds.
Middle Oolite.	150	Upper calcareous grit.	Calcareous sandstone; with ammonites, and other shells.
		Coralline oolite.	Rubbly impure limestone; with echinida and shells, and local beds of coral.
		Lower calcareous grit.	Calcareous sandstone; ammonites, and other shells.
		Oxford clay.	Blue clay, brown on the surface, with concretions of argillaceous limestone. *Gryphæa dilatata.*
		Kelloways rock.	Calcareous sandstone; full of casts of fossils. *Ammonites Calloviensis.*
Lower Oolite.	130	Cornbrash.	Thin, impure, compact limestone; with shells.
		Forest marble and Bradford clay.	Bluish, or gray, thin-bedded limestone and clay, with concretions of calcareous sandstone.
		Bath or great oolite.	Shelly, compact, and arenaceous limestone, in several beds. Shells, corals, *pentacrinus*, apiocrinus, *megalosaurus*, *pterodactyls.*
		Fullers' earth beds.	Calcareous and argillaceous alternations, with local deposits of fullers' earth.
		Inferior oolite.	Brown and ferruginous limestones, passing into ferruginous sands and sandstones in the Midland counties. Shells.
		Sands.	Containing masses of concretionary limestone, with shells.
Lias.	350	Upper lias shales.	Abundance of saurians and shells; *belemnites.*
		Marlstone rocks.	Full of shells, terebratulæ, pectines, *avicula inequivalvis.*
		Middle lias shales.	Gryphæa ammonites, &c.
		Lias limestone.	Gryphæa incurva, and other shells.
		Lower lias clay.	Passing into the coloured marls of the poikilitic system.

Range through England.

From Redcar Cliff, a little to the south of the Tees, to the coast of Dorsetshire, the rocks of the oolitic system extend in a continuous band, but with a very irregular outline. The course is nearly due south as far as Newark, trending thence to the southwest. The widest part of this zone is in the midland counties, where it expands to a breadth of nearly forty miles. This area constitutes in general a dry upland calcareous tract, having a steep escarpment towards the west, and a gentle slope towards the east, and forming the division between the eastern and western drainage of the island.

This calcareous tract is divided, however, into a series of longitudinal furrows and ridges, the former scooped out of the yielding clays, the latter composed of the more durable materials of the limestone of each formation, as shown in the annexed diagram.* The Wealden forms no part of this continuous band, but is chiefly exposed by a disruption and denudation of the chalk in the counties of Kent and Sussex, some slight traces of it being exhibited in the Vale of Wardour, in Wiltshire, in the Isles of Wight and Purbeck, and on the coast of France.

Between Paris and Metz a zone of oolitic limestones and clays is crossed, similar to that of the midland counties of England, but with a reversed dip, the escarpments of the limestones being towards the east.

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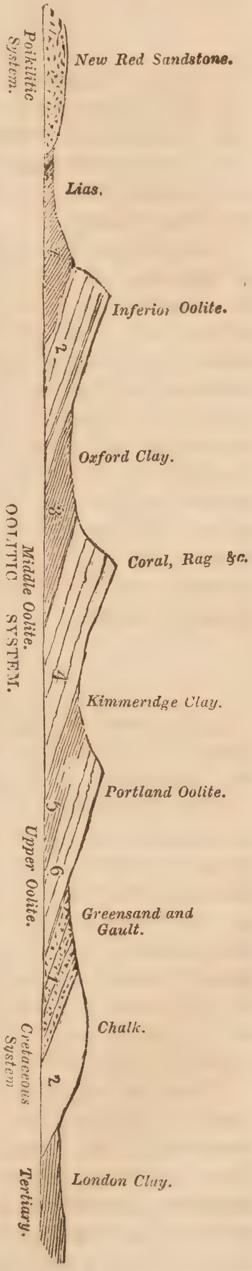

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* In fig. 60, the succession of British strata was shown, from the chlorite slate to the poikilitic system; this diagram continues the series to the tertiary deposit of the London clay, upon which, on the coast of Norfolk and Suffolk, rest the miocene and pliocene beds of the coralline, red, and Norwich crag.

Lias Formation.

Subdivisions.

1. Upper lias marls and shales.
2. Marlstone rocks.
3. Middle lias shales.
4. Lias limestones.
5. Lower lias clay, sometimes passing into the red marls of the poikilitic system.

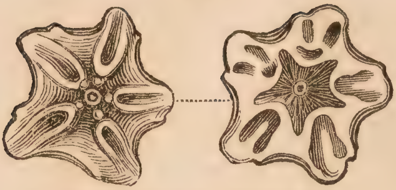
Lias, originally an English provincial name for a peculiar kind of limestone, is now very generally applied to a group of strata of considerable thickness which is the most widely diffused of the oolitic rocks, and preserves a remarkable uniformity of mineral character through a great part of Europe. Its prevailing character is argillaceous, with strata of argillaceous limestone, (the calcareous deposits prevailing in the lower part of the series,) separated by narrow partings of dark clay, which impart to quarries of this rock a striped or riband-like appearance. The most common hue of the limestones is blue, but it is sometimes white. In Bavaria, Westphalia, and the vicinity of the Hartz, the lower part of the formation passes into an arenaceous deposit, which is one of the rocks known to the Germans by the name of Quadersandstein.

Range.

In England the upper part of the lias formation constitutes the base of the Yorkshire Moorlands, and is seen in the cliffs between the Peak alum works, near Whitby, on the south, and Redcar Cliff on the north. It is likewise exposed in the denudation of the Esk, and in the other hollows intersecting those hills, crops out from beneath the sandstones which constitute their summits, and spreads over the low plain lying to the westward of them. The course of this tract of lias follows the sinuosities of their western escarpments, from the mouth of the Tees, first southeast, with a breadth exceeding on an average five miles, as far as the banks of the Derwent, when its breadth is considerably diminished, and in some places, particularly near Bishop Wilton, it is almost concealed by the overlapping chalk of the Wolds.

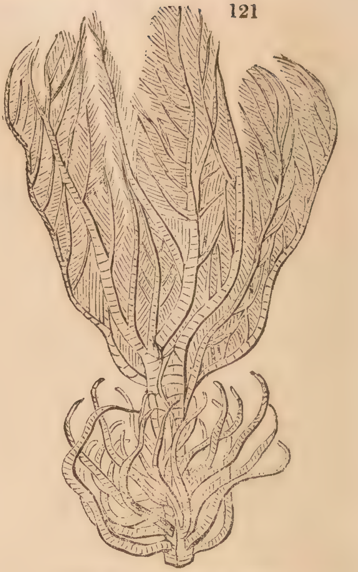
From the right bank of the Humber, the lias ranges nearly south to Newark, and thence southwest to Gloucester, with a continuous, but irregular outline, passing Gainsborough, Bingham, Leicester, the quarries of Burton-upon-Soar, Lutterworth, Southam, Stratford-upon-Avon, to Evesham. From this place, a projection runs out northwards from the general boundary for about fifteen miles, thence returning southward by Pershore,

120



Section of joints of Pentacrinus briareus.

121



Pelvis of Pentacrinus briareus.

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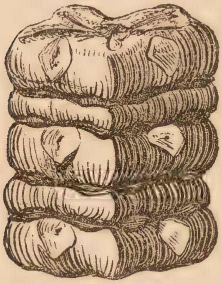

Stem of Pentacrinus briareus.

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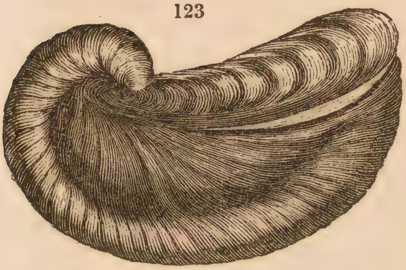

Gryphæa incurva

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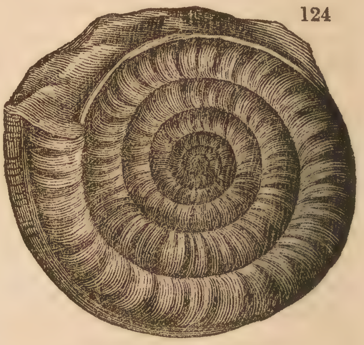

Ammonites Conybeari.

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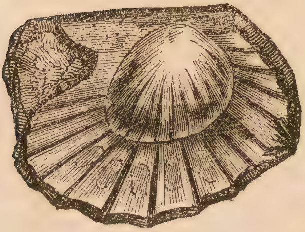

Avicula inequivalvis.

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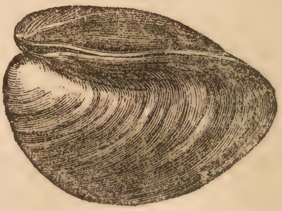
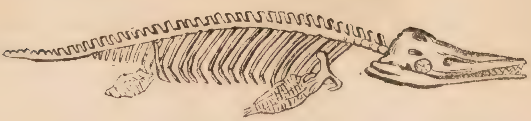


Plagiostoma giganteum

127



Ichthyosaurus communis.

Tewkesbury, Gloucester, and Berkeley to the banks of the Avon, near Keynsham.

Throughout this long tract, the greatest breadth of which, extending to twenty miles, is between Oakham, in Rutlandshire, and Stow, in Gloucestershire, the area occupied by the lias formation is bounded continuouly on the west by the marls and sandstones of the poikilitic system, and on the east by the escarpment of the inferior oolite, at the foot of which it forms a broad vale, but sometimes constitutes a part of the escarpment. South of the Avon, the course of the lias to the cliffs of Lyme Regis becomes very irregular among protruded masses of older rocks and outliers, and promontories of more recent formations. South of the Mendip Hills, it throws off several projecting tongues, the longest of which extends from Somerton to about five miles beyond Watchet. From the southern bank of the river Parrot, near Langport, the lias proceeds southwards by Ilminster, passing beneath some outlying masses of the overlapping cretaceous rocks to the coast at Lyme Regis.

Great Outlier in Shropshire. A detached portion occurs on the coast of Glamorganshire, at Aberthaw, opposite Watchet, but the most remarkable outlier of lias is that lately discovered by Mr. Murchison, near Whitchurch, in Shropshire, fifteen miles long, and nearly fifty distant from any other portion of this formation, thus constituting a monument of the extensive denuding action to which it has been exposed.

The thickness of the lias has been already stated at about 1000 feet. It nowhere in England attains a greater elevation than 500 feet above the sea. The points where it may be best examined are the cliffs of Whitby, Watchet, Aberthaw, and Lyme Regis.

ORGANIC REMAINS.

Zoophytes, Echinida, and shells.

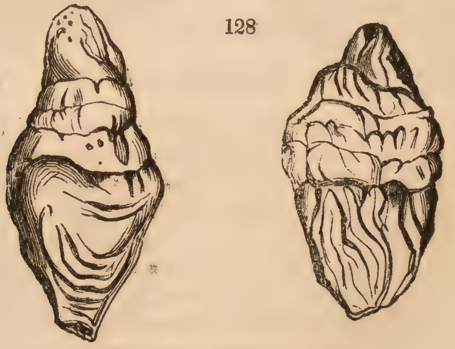
The fossils of this formation constitute a well-characterized group, composed of species chiefly marine and littoral. Corals, echinida, and stellerida, are rare; crinoidea are common, particularly the genus pentacrinus (120—122). It contains conchifera (bivalves) of all orders. The prevailing genera are terebratula and gryphæa (123), the last in such abundance as to have given rise to the Continental name for the formation of Calcaire à gryphites. It likewise contains several species of the genera plagiostoma, (126) modiola, and pholodomya, avicula inæquivalvis (125) is common to the upper lias and inferior oolite. The ancient genus spirifera terminates with this formation. Cephalopodous molluscs (chambered univalves) are abundant, of the genera ammonites (124), belemnites, and nautilus.

Fishes and Reptiles.

The fishes of the lias, as well as of the whole oolitic group, to which they are generically related, belong to the ganoid order of Agassiz, distinguished by a protecting cuirass, extending from the head to the rays of the tail, and composed of bony rhomboidal scales covered with enamel. Reptiles are numerous. The most remarkable are the marine genera, ichthyosaurus and plesiosaurus, in which, by a wonderful modification of structure, the saurian type was adapted for a constant residence in the sea.

Ichthyosaurus (127). In the ichthyosaurus, some species of which must have exceeded thirty feet in length, the general form of the porpoise was combined with the head of a lizard and the teeth of a crocodile. The power of rapid motion through the water, indicated by the form of the vertebræ, doubly concave like those of a fish, the ease and rapidity with which it must have been able to elevate and depress itself by means of paddles, like those of a whale, and a sternal arch, like that of the ornithorynchus of Australia, and the powers of vision afforded by enormous eyes defended by a circle of bony plates, as in turtles and lizards, must have rendered it a formidable tyrant of the deep, and must have admirably adapted it for supplying in the economy of nature, the place of the predaceous family of sauroid fishes of the older epochs, which had now become extinct. We have ample and curious evidence of its voracity and of the nature of its prey, in the discovery within the skeleton of the half-digested remains of fishes and small ichthyosauri, and of the fossil feces containing the same remains strewed for miles over the bed of the liassic sea. (128.)

128

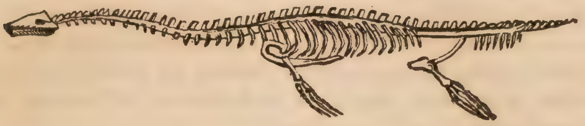


Coprolites of Ichthyosaurus.

This genus is most extensively developed in the lias, but has been discovered in the muschelkalk and in the lower formation of the cretaceous series.

Plesiosaurus. In the plesiosaurus (129), to a structure somewhat analogous, but less adapted for rapid motion through the water, was added a small head and a long neck, exceeding in the number of its vertebræ that of the swan, and from its general organization it is probable that it swam on, or near to, the surface, and frequented shallow water, where it lurked among weeds, and darted out its long and flexible neck to seize its prey.

129



Plesiosaurus dolichodeirus.

Sudden Inhumation of Organic Remains.

One of the most remarkable circumstances attending these fossil remains is, that they appear to have met with sudden destruction and immediate envelopement in sediment, if, as Mr. De la Beche has observed, they were not buried alive.

The evidence of this sudden inhumation consists in their perfect state, scarcely a bone or scale being removed, as would have happened had they been exposed even for a short time to the putrefactive process, and sometimes, as before remarked, the contents of the intestines are found within the pelvis. Another proof of sudden inhumation in the lias, is afforded by the ink bags of a species of loligo, which are frequently found at Lyme Regis, distended with the ink in a dried state, so perfectly preserved as to be capable of being used for the same purposes as Indian ink, which is obtained from an Oriental species of existing loligo. "Cuvier," says Dr. Buckland, "drew his figures of the recent sepia with ink extracted from its own body; I have drawings of the remains of extinct species prepared also with their own ink. With this fossil ink I might record the fact, and explain the causes of its wonderful preservation. I might register the proofs of instantaneous death detected in these ink bags, for they contain the fluid which the living sepia emits in the moment of alarm; and might detail the evidence of their immediate burial, afforded by the retention of the forms of these distended membranes, since they would speedily have decayed and spilt their ink, had they been exposed but a few hours to decomposition in the water."*

In these facts we have proof of sudden irruptions of muddy water, from time to time, destroying many marine animals, and burying them in sediment; but, on the other hand, we have also evidence of the lapse of a long period of time occupied in the deposition of the component members of the lias. This evidence consists in the immense quantity of molluscs, which arrived at maturity between these successive invasions of mud, and also in the lines of coprolites or fossil feces at various levels, the upper surface alone having suffered partial decomposition from the action of water before they were protected by muddy sediment.

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* Bridgewater Treatise, vol. i. p. 307.

The few vegetable remains found in the lias, consist of coniferous wood and cicadiform plants.

Lower Oolite.

Next to the lias in the ascending order succeeds the inferior oolite, a complicated and varying group of oolitic, shelly, and arenaceous limestones, flaggy and concretionary sandstones, and clays containing locally subordinate beds of fullers' earth. In the neighbourhood of Bath, where its thickness is between 400 and 500 feet, the following subdivisions have been established, commencing with the upper part:—

Subdivisions.

1. Cornbrash limestone.
2. Forest marble group, including the Bradford clay.
3. Bath or great oolite.
4. Fullers' earth beds.
5. Inferior oolite.
6. Sandstone.

The Sandstone, which forms the base of the formation, passes insensibly into the upper lias shales, by the admixture of various loamy and marly beds towards the lower part.

The inferior oolite, the type of which is at Dundry Hill, near Bristol, and in the cliffs near Bridport, is very generally distinguished by the brown tinge imparted to it by a large portion of disseminated oxide of iron, and frequently contains much siliceous matter. In the midland counties it becomes more arenaceous, and passes into ferruginous sand and sandstone, a broad tract of which prevails in the northern part of the counties of Oxford, Northampton, and Rutland.

The fullers' earth beds are a calcareo-argillaceous deposit, containing one or more indurated rocky strata, and frequent courses of soft rubble-stone, in which calcareous matter predominates. Blue and yellow clays, applicable to the purposes of fullers' earth, alternate locally with these.

Bath or Great Oolite, a calcareous mass varying in thickness from 130 to 200 feet, the softer beds of which afford the well-known Bath freestone. It usually occurs in thick-bedded masses, which thin off if traced to any distance. The arenaceous strata which accompany it often show oblique lamination.

Mr. Lonsdale observes, that a thorough acquaintance with this rock, illustrates the influence which organic remains have on the external character of rocks. When free from fossils it presents a uniform texture, yields easily to the saw, and is well adapted to the chisel of the sculptor. Beds in which shells abound acquire the texture of forest marble, and towards the top of the series, where polyparia exist, it assumes the appearance of some varieties of the coral rag.*

The Stonesfied slate, so remarkable for the mixture of marine and terrestrial remains, has lately been proved by Mr. Lonsdale to belong to the lower part of the great oolite, and not, as formerly supposed, to the forest marble. This calcareous slate consists of two beds of thinly laminated oolitic limestone, each about two feet thick, and separated by a bed of calcareous sandstone. The limestone is extracted by means of galleries about six feet high driven into the side of the hill, the sandstone and refuse being piled up to support the roof. The slate, on being struck with a mallet, after exposure to a winter's frost, separates into laminæ, sufficiently thin to afford a coarse roofing material. A similar calcareous slate is worked at Easton and Collyweston, in Northamptonshire.

The Forest Marble, a bluish or gray thin-bedded limestone, intermixed with oolitic particles. It is associated with strata of clay and sand, the former known by the name of the Bradford clay, the latter containing concretions of calcareous sandstone. The name of Forest marble is derived from the occurrence of this rock in Whichwood Forest, in Oxfordshire, where some of the more compact beds have been long worked as a coarse marble.

Cornbrash, a hard, compact, and impure limestone, containing shells, and generally occurring as a thin rubbly deposit, but sometimes composed, as near Malmesbury, of thick strata of crystalline limestone, associated with beds of sand and sandy clay.

Oolitic Coal Fields of Scarborough and Brora.

Such are the several subdivisions of the lower oolite formation in the south of England. It has already been stated that some of the calcareous groups become more arenaceous in the midland counties. On the coast of Yorkshire, the cornbrash appears to be the only member of the series that is constant, the rest of the mass consisting of alternations of sandstone and dark clays, full of land plants, associated with ironstone and seams of coal, and divided into an upper and lower series by a thin oolitic limestone, supposed by Professor Phillips to represent the great oolite. Some of the beds of coal are sufficiently thick to be worked for the supply of the neighbourhood, though the coal afforded by them is of inferior quality.

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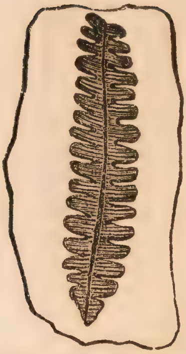
* Transactions of the Geological Society.

At Brora, on the coast of Sutherland, is a similar coal field, about twenty miles long and three broad, where Mr. Murchison found sandstones and shales, containing belemnites, ammonites, and leaves and stems of plants, associated with beds of coal, the plants identical with those of the oolitic coal field of Yorkshire.

Range of lower Oolite through England.

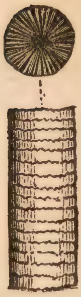
A broad but irregular tract of the rocks of this formation, lying north of Scarborough and Kirby Moorside, bounded on the east by the Northern Ocean, and on the west by the plain of the lias, constitutes the eastern moorlands of Yorkshire, and to this district the carboniferous shales and sandstones, representing all the subdivisions of the inferior oolite below the cornbrash, are nearly, if not exclusively, confined. The calcareous portion, however, extends in a narrow belt to Kirby Underdale, where it is covered by the chalk, but reappears a little south of Market Weighton, and ranges thence to the Humber. From the southern bank of that river to Lincoln, the rocks of this formation are confined to a narrow tract, and consist almost exclusively of the great oolite; but to the south of Lincoln they gradually expand, and the series become more fully developed, the eastern boundary passing near Sleaford, Peterborough, Bedford, Buckingham, Witney, and Malmesbury, to Frome, and the western boundary (disregarding the sinuosities of its conjunction with the lias) may be described as ranging by Grantham, Uppingham, Northampton, Banbury, Stow, Cheltenham, Gloucester, and Wickwar, to Frome. Within this area, the cornbrash and the great oolite may be traced continuously on the east, and the inferior oolite is represented by the ferruginous sandstone and reddish brown sands on the confines of the counties of Lincoln and Liecester, in the hills about Grantham, in the vale of Belvoir in the counties of Rutland and Northampton, and the northern part of Oxfordshire. The southern portion of that county, and the range of the Cotswold Hills through Gloucestershire, exhibit a complete series of the subdivisions of this formation. From Frome, they hold a devious and irregular course through the counties of Somerset and Dorset to the sea-coast at Bridport.

130



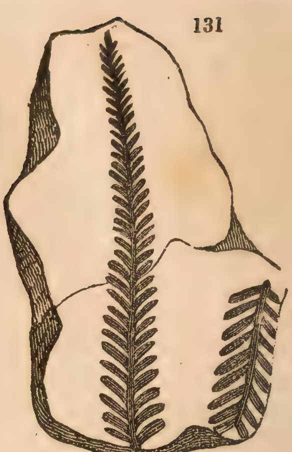
Pterophyllum Nelsoni.

132



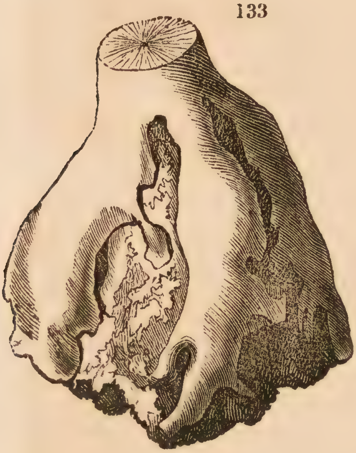
Stem of Apiocrinus rotundus.

131



Pterophyllum pecten, (Scarborough.)

133



Root of Apiocrinus rotundus.

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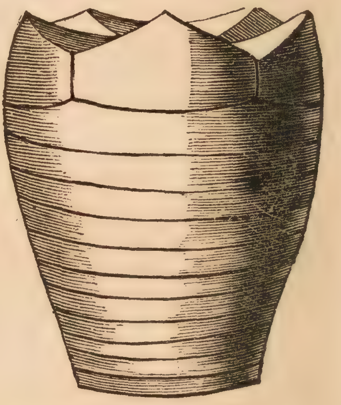
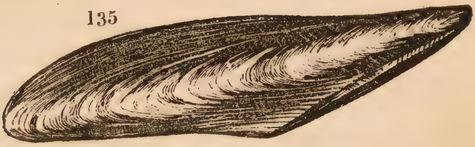


Pelvis of Apiocrinus rotundas.

135



Gervillia acuta.

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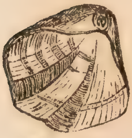
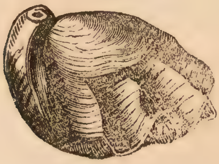


Terebratula coarctata.

137



Terebratula maxillata.

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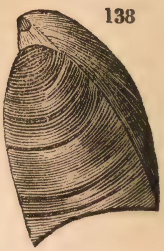


Terebratula digona.

ORGANIC REMAINS.

The Plants distinct from those of the Carboniferous System.

The organic remains of the inferior oolite are more varied than those of the lias. The plants, which occur in local deposits, consist chiefly of cycadeæ, ferns, and equisetæ. Those which approach most nearly to the fossil plants of the coal measures, are the ferns (130, 131); but even when belonging to the same genera, they are specifically distinct. There are no calamites, lepidodendra, sigillariæ, or stigmariæ.

Zoophytes.

Corals of many genera, accompanied by radiaria, of the genera pentacrinus and apiocrinus (132—134), are found in this formation generally, but chiefly in the great oolite. At Bradford, near Bath, the surface of the great oolite is covered with roots of Apiocrinus rotundus, still remaining on the spot, where they grew, while the stems lie prostrate in, or are scattered through the superior stratum of Bradford clay.

Shells, Fishes, and Crustaceans.

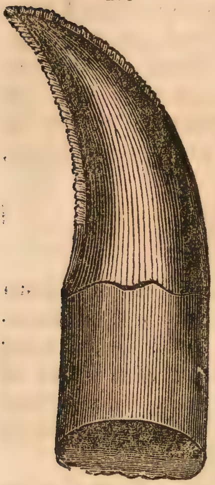
Conchifera of all orders are numerous. The genera avicula plagiostoma, pecten, modiola, and gervillia (135), become more developed than in the lias. They are accompanied by terebratulæ, some species of which, as Terebratula coarctata and maxillata, (136-7) are characteristic of this fomation; others, as Terebratula digona (138), have an extensive range through the oolitic series. Cephalopoda, of the genera enumerated under the head of the lias, are also abandant, accompanied by an increase of herbivorous molluscs. The remains of fishes and crustacea are also met with.

Saurians.

The Saurians are of the genera ichthyosaurus, plesiosaurus, crocodilus, megalosaurus, and pterodactylus. The calcareous and sandy strata of Stonesfield, in Oxfordshire, are celebrated for having yielded the only remains of mammalia which have yet been found in any strata of greater antiquity than the tertiary deposits. The beds, only six feet thick, contain a mixture of marine and terrestial exuviæ, which proves them to have been formed at the bottom of a sea near the shore. Fragments of land plants, bones of didelphys, megalosaurus, pterodactyls, with remains of insects, are mingled with ammonites, belemnites, nautili, and other marine shells.

Megalosaurus. The megalosaurus was a gigantic carnivorous reptile, partaking of the structure of the crocodile and monitor, and from forty to fifty feet in length, as appears from the proportions of the numerous bones which have been discovered; though the entire skeleton has never yet been met with. The bones of the thigh and leg are not solid in the centre, as in crocodiles, but are furnished with large medullary cavities, like the bones of terrestrial animals. The form of the jaw shows that the head was terminated by a straight and narrow snout. The teeth prove it to have been carnivorous, combining a mechanism analogous to that adopted in the structure of the knife, the sabre, and the saw (139). These remains are chiefly found in the calcareous slate of Stonesfield but as they have also been met with in the Wealden, the megalosaurus probably existed through the whole oolitic epoch.

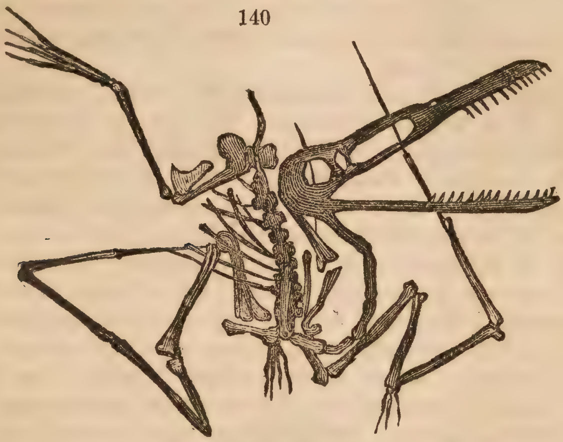
139



Tooth of Megalosaurus.

Pterodactyl. Pterodactyls, which accompany these remains at Stonesfield, have also been found in the lias at Lyme Regis, and in the lithographic slate of Solenhofen and Aichstadt. A winged lizard is unknown in the existing creation, but the pterodactyl exhibits a curious adaptation of the saurian form to the purposes of flight. Eight species have been found, varying from the size of a snipe to that of a cormorant. The external form approached that of the bat; the fore-arm being elongated, to support a membraneous wing, from which projected fingers, terminated by long hooks, like the curved claw on the thumb of that winged mammalian (140). It had the small skull observable in reptiles, joined to a neck resembling that of a bird, and terminating in a beak armed with at least sixty sharp teeth. This length of neck was produced, not by numerous cervical vertebræ, but by the elongation of a few, not exceeding six or seven in number, whereas, in birds, they vary from nine to twenty-three. The back, again, was much longer than in birds, in which the dorsal vertebræ vary between seven and eleven; whereas, in pterodactyls, they are about twenty. The ribs, moreover, thread-shaped and round instead of flat, and the metatarsal bones of the foot distinct, instead of being consolidated into one, with other peculiarities of structure, which cannot be enumerated in this brief sketch, to say nothing of the teeth, proclaim it of the lizard family, and preclude the possibility of its being a bat or a bird. The structure of the toes renders it improbable that it suspended itself after the manner of bats; and the size and form of the foot and leg show that it had the power of standing firmly on the ground. The smaller species, as suggested by Cuvier, may have fed on the large libellulæ, and coleopterous insects, which accompany these fossil remains in the quarries of Stonesfield and Solenhofen; but the larger kinds must have required a different prey, and probably fed on fishes which they caught by darting down on the water like some sea-fowl, or on the small marsupialia, which were joint inhabitants with them of the islands of the oolitic ocean.

140



Pterodactylus longirostris.

Marsupialia.

Of these, only three jaws have been found, belonging to two species about the size of a mole. By the double roots of the teeth, they are shown to have belonged to the class mammalia, and the form of the crowns identifies them with the order marsupialia.*

MIDDLE, OR CORALLINE OOLITE.

Subdivisions.

Upper group, or coral rag.	Upper calcareous grit. Coral rag and oolite. Lower calcareous grit.
Lower group, or Oxford clay.	Oxford clay. Kelloways rock.

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* Buckland's Bridgewater Treatise, vol. i. p. 73, 121, 221, 235.

Oxford Clay. A strong, argillaceous deposit, of great thickness, generally of a dark-blue colour, but becoming brown by exposure on the surface, and containing septaria, and concretions of argillaceous limestone, divided by veins of calcareous spar. Near the bottom of this clay is a bed of calcareous sandstone, abounding in fossils, and usually known by the name of the Kelloways rock. Below this, is another bed of clay. The argillaceous strata are sometimes mixed with bituminous matter, affording an inflammable shale, or imperfect coal.

Coral Rag. This deposit consists of two beds of calcareous sand, separated by a bed of limestone. The lowest arenaceous bed, which rests immediately on the Oxford clay, is a yellow, quartzose sand, containing about 30 per cent. of calcareous matter. The limestone is a loose rubbly stone, sometimes almost wholly composed of corals, which occur indifferently in the top, bottom, or middle of the bed. The upper arenaceous deposit is a calcareous freestone, of a close texture, full of comminuted shells and frequently indistinctly oolitic, but occasionally passing into beds in which the globular concretions are much larger than in the other oolites. These varieties have obtained the name of Pisolite. Oblique lamination is by no means uncommon.

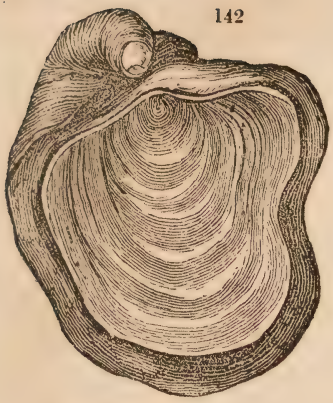
Geographical Extent. In Yorkshire, this formation composes a series of tabular hills, extending westward, from the coast between Filey and Scarborough, to Hambleton; the calcareous grits and coralline oolite forming their summits, and a gray, argillaceous earth, with a ferruginous or argillaceous sandstone, which contain, respectively, the fossils of the Oxford clay and the Kelloways rock, appearing on their northern slopes.

From Hambleton, the inferior boundary of the formation turns southeast, and passes under the chalk wolds at Acklam. The argillaceous portion reappears on the banks of the Humber, (the calcareous part of the formation being absent,) ranges through the counties of Lincoln, Bedford, and Buckingham, following the eastern boundary of the lower oolite formation to Ottmoor, near Oxford. Here the coralline oolite again appears, and accompanies the Oxford clay westward to Cricklade, and thence southward, by Malmesbury, Calne, Melksham, Wincanton, and Sturminster, to near Beaminster, where it is covered by the chalk. but emerges from beneath it on the coast, near Melcombe Regis.

ORGANIC REMAINS.

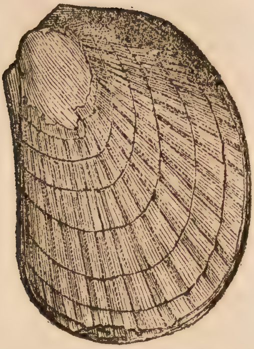
Many of the fossils of this formation are common to this and the inferior oolite. The following are considered characteristic:—Ammonites calloviensis (141), Kelloways rock; Gryphæa dilatata (142,) Oxford clay; Ammonites vertebralis, Plagiostoma rigidum (143,) Clypeus dimidiatus, Cidaris florigemma, Astrœa tubulifera, and Caryophylla annulata, coral rag. Echinida (144—146), par-

142



Gryphæa dilatata, (Oxford Clay.)

143



Plagiostoma rigidum.

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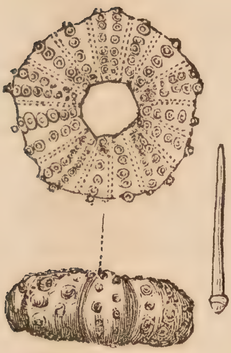
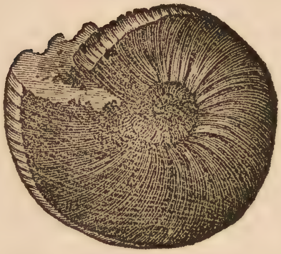


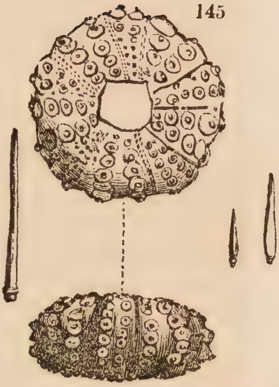
Cidaris monilipora.

141



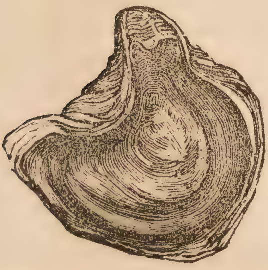
Ammonites calloviensis, (Oxford Clay and Kelloway Rock.)

145



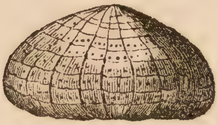
Cidaris coronata, (Coral Rag.)

147



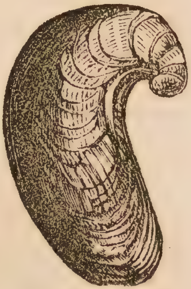
Ostrea deltoidea, (Kimmeridge Clay.)

146



Galerites depressus, (Coral Rag and Oxford Clay.)

148



Gryphæa virgula, (Kimmeridge Clay.)

ticularly the genus cidaris, are abundant in this formation, and are also found in the coralline limestones of other parts of the oolitic system. The neighbourhood of Weymouth and Calne, in the south of England, and of Scarborough, in the north, afford the best types of the formation.

UPPER, OR PORTLAND OOLITE.

Subdivisions.

1. Portland oolite.
2. Kimmeridge clay.

Kimmeridge Clay. A blue, lead-coloured, or bluish-yellow clay, containing crystals of selenite, and occasionally bituminous shale, sufficiently inflammable to be used as fuel, and thence called Kimmeridge coal. This subdivision is best exposed in the cliffs at Kimmeridge, and in the Isle of Portland.

Portland Oolite. A limestone of variable character, and locally oolitic, quarried extensively in the isles of Purbeck and Portland, which have supplied most of the building stone used in the neighbourhood of London.

Range.

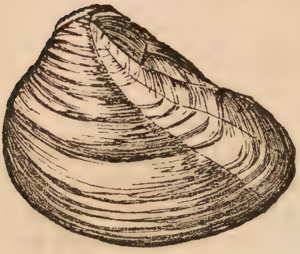
This formation in its range through England, is less continuous than the other oolites. The Kimmeridge clay fills the vale of Pickering, in Yorkshire, from Filey Bay to Helmesley. From the south bank of the Humber to Spillsby, it is seen as a narrow band, cropping out from beneath the greensand and chalk of Lincolnshire, is concealed for a time by the alluvial deposits of the fens, but it reappears on the western side of Norfolk, a little north of Castle Rising. The course of the Ouze, from Lynn to near St. Ives, is almost wholly in this formation, which ranges in a narrow band through part of Huntingdonshire and Bedfordshire, and expands in Buckinghamshire, where the Kimmeridge clay and Portland oolite spread over the vale of Aylesbury. The Kimmeridge clay is seen in Shotover Hill, Cumnor Hurst, and Farringdom Clump, capped by the oolite, and by sands of the cretaceous system. It ranges by Swindon, Wotton Basset, Westbury, and Sturminster, parallel to the coral rag formation, and passing under the chalk, emerges again near Weymouth, and in the isles of Portland and Purbeck.

CHARACTERISTIC FOSSILS.

The fossils of this formation have a general analogy to those of the other oolites. Ostrea deltoidea (147), and Gryphæa virgula

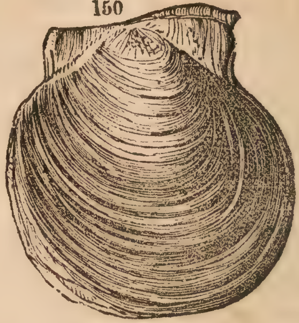
(148), are characteristic of the Kimmeridge clay. Cardium dissimile, Astarte cuneata, Trigonia gibbosa (149), and Pecten lamellosus (150), of the limestone.

149



Trigonia gibbosa.

150

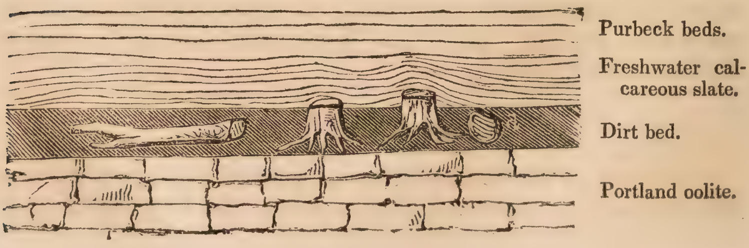


Pecten lamellosus.

Submerged Forest of the Dirt Bed. But the most important organic remains of this part of the series, because they prove gradual elevations and depressions of the bed of the sea, converting it into dry land, and again submerging it, are the stumps of trees and other plants still rooted on the place of their growth, on the surface of the Portland oolite, itself a marine formation, covered by the estuary deposit of the wealden, on which again are imposed the oceanic beds of the chalk.

These trees and plants occur in a layer of black carbonaceous matter, from twelve to eighteen inches thick, interspersed with rounded pebbles, and known to the workmen by the name of the dirt bed. It bears evident marks of having been an ancient vegetable soil, and contains prostrate trunks of coniferous trees, from twenty to thirty feet long, and branching at the height of seventeen or twenty feet; there are also stumps standing erect, for a height of from one to three, and in some instances six feet, and rooted in their native soil. They are accompanied by remains of cycadeæ of the genera cycas and zamia, likewise in the attitude of growth. These are a family holding an intermediate position

151.



between coniferæ, palms, and ferns. The existing species are all inhabitants of the equinoctial parts of America and Asia, the Cape of Good Hope, and Australia. None of them are found in Europe. The stumps are covered by thin layers of a freshwater calcareous slate, the strata of which, horizontal elsewhere, form hemispherical concretions round the top of the stumps.

Proofs of repeated Oscillations of the Surface.

In these phenomena we have the most decided evidence of the surface of the Isle of Portland having been converted into dry land, and having remained in that state at least sufficiently long for large coniferous trees to attain their full growth, and for the accumulation of vegetable soil more than a foot thick; and it is impossible to explain the intercalation of this terrestrial accumulation between two marine deposits on any other supposition than that of the submergence of the land. The very existence of the dirt bed in such a situation proves the submergence to have been gradual, and in still water, for such an accumulation of loose and light vegetable mould could not have been exposed to violent currents and the action of the breakers without being swept away. There is, moreover, no trace whatever of sudden and violent disturbance—no want of conformity between the Portland oolite and the dirt bed. In Lulworth Cove, where the dirt bed and its imbedded stumps are inclined to the horizon, at an angle of 45°, the wealden formation, the greensand, and the chalk, are still conformable with it, and they all appear to have been raised at the same time by a subsequent convulsive movement, which produced the anticlinal axis of the Weymouth district, and the elevated strata of the Isle of Wight. We have thus proofs of movements of elevation of two distinct kinds: the one tranquil, gradual, and capable of elevating marine deposits without disturbing their horizontality, like that which is now in progress in Sweden, and which, according to Mr. Darwin, is taking place in the Pacific Ocean; the other sudden and violent, like those disturbances which have fractured, upheaved, and thrown into inclined and even vertical positions, the strata of the slate rocks, and of the carboniferous systems.

Proofs of Lapse of Time.

The superincumbent freshwater beds of the wealden not only afford additional proofs of the tranquil and gradual submergence of the dirt bed, but prove a long interval of time to have elapsed while the process was taking place, and from the occurrence of more than one dirt bed, (for two others have been discovered in the Portland oolite, at different levels, one of them containing cycadeæ still rooted,) it appears that several oscillations of the land and sea took place before the final submergence of the Portland oolite beneath the fluviatile waters of the wealden and the oceanic deposit of the chalk. Of the extent of the land on which the cycadeæ and coniferæ of the Isle of Portland grew, we have no means of judging beyond this, that traces of the dirt bed have been found by Dr. Buckland near Thame, and by Dr. Fitton in the Boulonnois.

Wealden Formation.

After the incidental mention which has so often been made of this formation, it is almost superfluous to repeat that it is a local freshwater, or rather estuary, deposit, not accompanying the other oolitic rocks in that broad band which ranges diagonally across the island, but exposed by a disruption and denudation of the chalk in the counties of Kent and Sussex, where it constitutes a district of clay and sand, known as the Weald of Kent and Sussex, and the forest tracts of Tilgate and St. Leonard. We are indebted to Dr. Fitton for a knowledge of the existence of this freshwater deposit, which before his researches had been confounded with the iron or Shanklin sand, belonging to the lower part of the cretaceous series.

Subdivisions.

The following are the subdivisions established in the wealden group, commencing with the uppermost:

1. Weald clay.
2. Hastings sands, including the Tilgate beds.
3. Purbeck or Ashburnham limestone and clay.

Purbeck or Ashburnham Beds. These are a series of limestones and shales, alternating with blue clay and marl, containing freshwater shells, in the Isle of Purbeck and on the coast of Dorsetshire, and resting on the Portland oolite.

They are there covered immediately by chalk, the superior members of the wealden being wanting. At Ashburnham, in Sussex, a similar series of limestones and clays, with subordinate beds of grit, ironstone, and sandstone, have been found to constitute the base of the wealden formation.

Hastings Sands. The Hastings sands, including the Tilgate beds, rendered so celebrated by the zoological researches of Dr. Mantell,* consist of irregular alternations of sand and sandstone, sometimes calcareous, of a gray, yellowish, or ferruginous colour, with occasional concretions of ironstone and layers of lignite. The sandstones sometimes assume a conglomerate form, and contain pebbles of jasper and quartz. These rocks constitute the forest ridge, or anticlinal axis, of the weald denudation, and extend along the coast from near Bexhill, in Sussex, to Ham Street, near Aldington, in Kent, in a range of cliffs 600 feet high, the strata dipping in opposite directions from Winchelsea as a centre. This group is exposed inland as far as Loxwood, in Sussex, its greatest breadth being at Crowborough Beacon near Tonbridge Wells, which is 800 feet above the level of the sea.

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* Geology of the Southeast of England.

The Wealden Clay. A tenacious blue clay, with subordinate beds of sandstone and shelly limestone, and layers of argillaceous ironstone. It forms an undulating valley, from five to seven miles broad, which encircles the central forest ridge above described, and separates it from the escarpments of the cretaceous series, constituting the North and South Downs. This valley, covered with natural woods, and affording a cold retentive soil, better adapted to the growth of timber than to cultivation, is called the Weald or Wild of Kent and Sussex. It extends from Pevensey, on the Sussex coast, to Harting Combe, near Petworth, on the west, and thence returns, by Tonbridge and Aldington, to the coast of Kent, between Hythe and Rye.

The calcareous beds occur in layers, varying in thickness from a few inches to more than a foot; they are of various shades of bluish gray, mottled with green and ochraceous yellow, containing freshwater shells in great abundance, imbedded in a compact calcareous base, capable of taking a slight polish, and elegantly marked on a polished surface with sections of shells. Though fallen into disuse this limestone was much employed in our cathedrals, and other ancient edifices, under the name of Petworth marble. It bears a considerable resemblance to the Purbeck beds, also used for the same purposes. The Petworth marble is coarser grained, and was employed for altar tombs and slabs of large dimensions. The shells contained in it consist almost exclusively of a large species of paludina, or vivipara. In the Purbeck marble, which is usually seen in the taper shafts of clustered columns, and other works requiring a fine grain, the shells belong to a smaller species of paludina. The Ashburnham beds are further distinguished by containing sections of freshwater bivalves of the genus cyclas.

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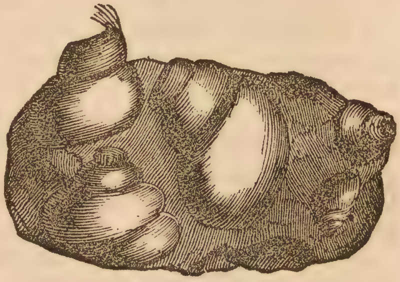

Paludina vivipara.

The wealden clay and the Hastings sands occur likewise in the Isle of Wight, where fine sections of them, covered by the lower greensand of the cretaceous system, are exhibited in the cliffs.

Organic Remains.

The organic remains of the wealden formation consist of the bones and scales of fishes, bones of saurians, and chelonian reptiles, fragments of land plants, the shelly covering of cypris faba, a small freshwater crustacean, several species of paludina, cyclas, unio, and melanopsis, all freshwater genera, occasionally in great abundance, mixed with a few shells of ostrea, cardium, pinna, and venus, genera inhabiting estuaries. The fishes belong to genera (pycnodus, hypodotus, and lepidotus) which are common to the whole oolitic group. Most of the species of hypodotus are supposed, from their structure, to have frequented coasts and the mouths of rivers.

The fossils of the different subdivisions partake of a general character, subject to some local distinctions. The remains of reptiles are most abundant in the Hastings sands; shells of paludina, in the calcareous group. The minor differences distinguishing the upper limestones of the wealden from the lower or Purbeck and Ashburnham beds, have already been described.

Plants.

The vegetable remains consist of ferns of the genera sphenopteris and lonchopteris, and of equisetæ, which appear to have been three or four feet high. These last are only met with locally, but where they occur they are very abundant. Mr. Mantell mentions several instances both of ferns and equisetæ in an upright position, as if gently covered with sand while growing.

Clathraria. Besides these are found petrified fragments of large plants, to which the names of clathraria and endogenites have been given. The former is covered externally with rhomboidal scales, to which the leaves appear to have been attached. It is considered by botanists as affording analogies to the existing genera cycas, zamia, yucca, and dracæna. Some seed vessels, known by the name of carpolites, are supposed to have been its fruit.

Endogenites. The only other large vegetable met with in this formation is Endogenites erosa. It is generally somewhat flattened, attenuated at the base, and swelling out at intervals like some of the cacti and euphorbiæ. These stems occur in the state of sandstone, the external surface of which is covered with a dark carbonaceous matter, and is scored with small meandering grooves and deep longitudinal furrows. The internal structure, as exhibited in a transverse section, proves it to have belonged to the class of monocotyledons. M. A. Brongniart refers it to the class of arborescent ferns with short stems.

Reptiles.

The remains of chelonian reptiles are confined to bones belonging chiefly to the freshwater genera emys and trionyx, with a few referrible to true chelonians or turtles. The saurians are of the genera plesiosaurus, crocodilus, megalosaurus, iguanodon, and hylæosaurus.

Iguanodon. Of these the most extraordinary was the iguanodon, both from its colossal proportions and its habits, as indicated by the structure of its teeth, which bore a considerable analogy to those of the iguana, a small herbivorous lizard, which inhabits the West Indies, and other parts of tropical America. The teeth of the iguanodon, differed from those of the iguana in several striking peculiarities, one of the most important of which is the difference in the form of young and adult specimens, showing that the iguanodon masticated its food like herbivorous mammalia. The young teeth are lancet-shaped, with serrated edges, resembling those of the iguana (153). In more advanced stages of growth (154), the point is found worn away and the crown ground down flat, exhibiting an appearance so unlike that of any fossil or recent saurian teeth, that when first shown to Cuvier he mistook them for those of an enormous hippopotamus. In the iguana, which nips or crops the vegetables on which it feeds, and swallows them without mastication, the teeth, when worn down, appear chipped and broken, not ground down in this manner.

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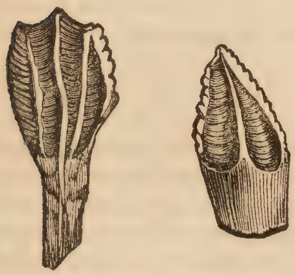

Young teeth of Iguanodon.

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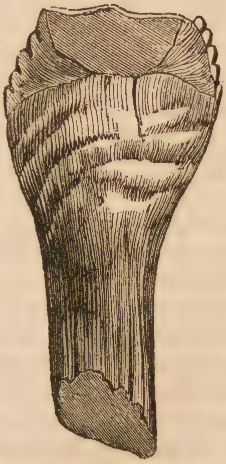

Adult tooth of Iguanodon.

The length of the teeth of the iguanodon is about three inches, or twenty times longer than those of the iguana. Enormous bones, not belonging to the megalosaurus, accompany these teeth, and are referred, with great probability, to the same animal; among others, the fragment of a thigh bone having a medullary cavity, as in the terrestrial mammalia, and thirty-two inches in circumference in its smallest part. Its length, when entire, must have been between four and five feet, exceeding in size that of the largest elephant. This femur bears the same proportion to the fossil teeth accompanying it that the corresponding bone in the living iguana bears to the teeth of that animal. Associated with these bones there has been found a curious appendage, which appears to have been a nasal horn, equal in size and similar in form to the smaller horn of the rhinoceros. We have here another analogy to the structure of the iguana, some species of which are furnished with a horny or bony protuberance on the head. The form of the bones of the feet and the large medullary cavities of the thigh bone, show that, like the megalosaurus, the iguanodon was adapted for motion on the land. The claw bone, which appears to have been protected by a nail, differed only in size from that of the iguana.

From a comparison of the dimensions of corresponding bones in an iguana five feet long, and in the iguanodon, Mr. Mantell has inferred the following astonishing proportions for the entire carcase of the latter:—

	Feet.	Inches.
Length from the snout to the tip of the tail - - -	70	0
Length of head - - - - - - - -	4	6
Length of body - - - - - - - -	13	0
Length of tail - - - - - - - - -	52	5
Height from the ground to the top of the head - - -	9	0
Circumference of body - - - - - - -	14	6
Length of thigh and leg - - - - - - -	8	2
Circumference of thigh - - - - - - -	7	6
Length of the hind foot from the heel to the point of the long toe - - - - - - - - -	6	6
Length of claw bone - - - - - - -	0	4
Horn - - - - - - - - - -	0	4

Though the remains of this enormous reptile were, till lately, found exclusively in the deposits of the wealden, it appears that its duration was not limited to that epoch, for a large portion of a skeleton confirming, in most points, the inferences drawn by Mr. Mantell, from the examination of numerous insulated bones, has recently been found in the Kentish rag, a marine limestone of the lower part of the cretaceous series. This carcase was probably floated out to sea, as the bones found in the wealden were drifted by rivers into an estuary.

Hylæosaurus. The hylæosaurus was of a less gigantic size, probably not exceeding twenty-five feet in length. Its most remarkable peculiarity consists in a series of bones which appear to have formed a fringe along the back, like the spines on the back of some of the modern iguanas. They are accompanied by large dermal plates, which probably had scales attached to them, and were lodged in the skin.

A considerable part of the skeleton of this animal was found with bones, either united or slightly dislocated; but maintaining a situation bearing some relation to the place they must have occupied in the living animal; and the position in which they occur is such as to show that the carcase must have floated from a distance in a partial state of decomposition, (the bones being dislocated, but held together by the muscles and tendons,) until it sank, and became enveloped in mud, forming a nucleus, around which collected the leaves of plants and the freshwater shells, enclosed in the block of stone in which it was found. Mr. Mantell's celebrated collection of these wealden fossils is now lodged in the British Museum.

Birds.

The wealden was, till lately, supposed to afford the earliest traces of the remains of birds, with the exception of those footmarks impressed on rocks in America, which are referred to the poikilitic era; but Lord Enniskillen has lately procured from the chalk a bone which Mr. Owen considers to have belonged to some long-winged natatorial bird allied to the albatross. In the wealden, Mr. Mantell has established the existence of several bones of grallatores or waders.

The Weald a Delta Deposit.

The strata of the wealden, after passing beneath the chalk of the western extremity of the denudation of the weald, reappear in the vale of Wardour, in Wiltshire, in a small patch, where they have the same relative position to the cretaceous rocks as in Sussex, the Isle of Wight, and the Isle of Purbeck. They are found also on the coast of France, near Boulogne, and at Beauvais, between Boulogne and Paris, in a denudation of the chalk like that of Sussex.

From the group of fossils above enumerated, from the abundance of terrestrial exuviæ, the scarcity of marine remains, and the total absence of ammonites, belemnites, trigoniæ, and other oceanic genera of the oolitic formation, there can be no doubt that the wealden deposits were formed in the delta of some river flowing through a country diversified with a variety of soils, and lying under a warm climate. The extent of that delta, 200 miles from east to west, or from Boulogne to Lulworth Cove, and 220 miles from southeast to northwest, or from Beauvais to Whitchurch, in Buckinghamshire, forming an area rather larger than that of the delta of the Ganges, or Mississippi, but smaller than that of the Niger, proves that the river constituted the drainage of some extensive tract of land; and this same conclusion may be drawn from the dislocated, broken, and rolled condition of the bones of the great saurian inhabitants of the land, since it shows that they must have been drifted a considerable distance.

Absence of Mammalian Remains.

The total absence of mammalian remains from such a deposit, though a negative fact, is of considerable importance, since it proves that they could not have been abundant at this epoch. The existence of marsupialia during an earlier part of the oolitic era, is established by the specimens found at Stonesfield, and is rendered probable at an era still more ancient by the footsteps impressed on the poikilitic sandstones of Cheshire and Saxony; but had mammalian animals, during the deposition of the wealden, borne the same proportion to saurians that prevails in existing tropical climates, some traces of their remains must ere this have been met with, since there is no reason why the skeleton of a terrestrial reptile, like the iguanodon, should be more likely to be discovered or preserved in the strata of a large delta, than those of mammalia analogous to the hippopotamus or tapir.

Oolitic Coal Field of Northern Germany.

The land from which the wealden strata were derived, must have been drained by other rivers flowing into other seas, and if we could discover more of these delta deposits, we might be able to point out the position, and obtain a proximate knowledge of the boundaries of that ancient land; but most of them are probably submerged beneath the present ocean, or covered by the cretaceous rocks, and had the anticlinal axis of the weald of Kent, in its range from east to west, passed but fifty miles, or even less, to the north of its actual line, we might have known little or nothing of the existence of one such delta, and of all the wonders which it has disclosed. One other similar deposit, however, has been recently found in the north of Germany, where M. Roemer has ascertained that the weald clay and the Hastings sands, the latter generally less ferruginous than in England, are accompanied by nearly all the fossils described by Dr. Fitton, in his memoir on the English rocks of this era. The shells are all fluviatile, with the exception of an astarte. According to this author, the wealden formation is exhibited near Helmstead, and extends westward from Hanover, by Minden, to Iburg and Rheine, near Munster in Westphalia, furnishing every where a very good coal, and thus affording another exceptional case of an oolitic coal field. The seams, from seven to ten in number, vary from one to three feet in thickness, and are separated by sandstone, which is sometimes only a few feet thick.*

This discovery, coupled with the fact of the increase of vegetable matter, in the carboniferous and oolitic systems of England, as we trace them towards the north, and with the occurrence of coal in the Isle of Bornholm, associated with rocks of all ages, from the true coal measures to the cretaceous system, points to the arctic regions of Europe for the situation of the land, which supported the tropical vegetation both of the coal measures and the wealden.

If, from the rapid thinning off of the wealden deposits, in the direction in which traces of the dirt bed occur, we suppose its detrital matter and organic remains to have been derived from that quarter, we are met by the fact, that the vegetable remains of the two formations, though agreeing in possessing a general tropical aspect, yet constitute two totally distinct groups.

Contemporaneous Marine Beds.

Contemporaneous with local deposits at the mouths of rivers, there must have been marine strata formed at a distance from the land, and traces of such strata, apparently intermediate both by position and fossils between the cretaceous and oolitic systems, have been found in the deposits containing pisiform iron ore, which occur in the department of Haute Soane, near Candern in the Brisgau, in parts of the Jura, and in Poland. There is, however, considerable difficulty in identifying them with the wealden, from the organic remains being exclusively those of the sea in the one case, and in the other, exclusively those of fresh or brackish water.

Geographical Distribution of the Oolitic System.

The preceding description of the oolitic rocks has been principally confined to the English series, as affording the most complete type of the system. There are but slight traces of them in other parts of the British Islands. On the eastern side of Scotland, they are confined to the coast between the Ord of Caithness and Dunrobin Castle, including the carbonaceous deposits of Brora already described, and some insulated patches on the shores of the Murray Frith. On the western side, they are found on the coast of the mainland at Applecross, and skirting the sound of Mull. They border the islands of Sky and Mull on the northeast, and form the northeast portion of the small island of Eig. In Ireland, they are confined to the district between Portrush and

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* Proceedings of the Geological Society, vol. iii. p. 324.

Belfast Lough, where they appear in coast sections, very slightly developed between the red sandstone and the chalk.

In treating of the general mineral characters of the rocks of the oolitic system, some of the localities on the continent of Europe where they occur have been already noticed, and their agreement or disagreement with the northern and southern types of England has been pointed out. An adequate notion of their intricate ramifications through France and Germany can only be obtained by consulting a geological map of those countries. They surround the cretaceous deposits of the Paris basin, from Caen, by Poitiers, to Mezieres and the Ardennes, spreading westward and southward of those mountains by Luxemburg, Metz, Nancy, and Dijon, to near Lyons. From Poitiers one branch runs southwest to Rochelle, and another southeast to the Cevennes, sweeping round again to the west along the northern flanks of the Pyrenees.

From near the eastern termination of that chain, the Jura kalk and calcaire à gryphites (oolite and lias) have a northeastern range, constituting the French and Swiss Jura. They are continued through Wurtemburg into Bavaria, along the north bank of the Danube, turning north at Ratisbon to the banks of the Maine at Banz, near Coburg, by Nuremburg and the district of Bayreuth, so celebrated for its ossiferous caverns. In Northern Germany, the lias resting on red marl is seen on the north of the Erzgebirge and round the Hartz.

The oolitic rocks, but under the altered mineral aspect already noticed, range eastward from Savoy through the Alps, on their northern side as far as Vienna, and on their southern side by Lago Maggiore, Lago di Guarda, and Belluno, to Laybach, whence branches are thrown off into Illyria, Dalmatia, and Greece. The limestone about Cracow, north of the Carpathians, is referred to this era. In its upper part are found those ferriferous deposits which have been mentioned as the probable marine equivalents of the wealden group of England. Rocks of the oolitic series occur in the Apennines, the Balearic Isles, Spain, and Mount Atlas.

Anomalous Mixture of Fossils in the South of Europe.

It is not only in their mineral characters that the oolitic rocks of the Alpine type differ from those of Northern and Western Europe; they are distinguished by a general scarcity of organic remains, and present at several points some anomalous mixtures of fossils of different geological epochs. At the Col du Chardonnet (Hautes Alpes), M. Elie de Beaumont has found calamites, sigillariæ, lepidodendra, and other plants of the coal measures, having beds containing belemnites above and below them; these beds, according to the same author, being continued to Digne and

Sisteron, where they contain other fossils characteristic of the lias. In the Gulf of Spezzia, also, Signor Guidoni discovered a mixture of belemnites, orthoceratites, and ammonites, most of the ammonites belonging to undescribed species. We shall see hereafter that the equivalents of the cretaceous rocks, in countries bordering the Mediterranean, contain fossils, which in the north of Europe are confined to the tertiary strata.

The general scarcity of organic remains in the oolitic rocks of Southern Europe has been ascribed to the prevalence of a very deep ocean over those regions, while sediment enveloping a great abundance of animal exuviæ were forming in the shallow seas of other parts of the European area; and the nature of the shells contained in the southern oolites, (belemnites, orthoceratites, ammonites,) all furnished with an apparatus for floating, appear to favour the hypothesis. The plants imbedded in the sandstones or macignos of Italy are also marine. The land plants of the Col du Chardonnet, belonging to the carboniferous era, may have lingered in some island of this southern ocean after they became extinct in those more northern regions from which the vegetable remains of the coal measures of England, France, Belgium, and Germany, appear to have been derived.

Igneous Rocks and Disturbances.

The oolitic system exhibits in Great Britain few instances of local disturbance by the intrusion of igneous rocks. The Cockfield basaltic dike in Yorkshire cuts the lias and lower oolites, producing the usual changes near the point of contact. Professor Sedgwick and Mr. Murchison found the oolitic rocks of Brora much fractured and disturbed as they approached the granite, and at the junction is a breccia, composed of fragments of all the beds of the series which occur on that coast, from which they infer that the granite was in this case upheaved in a solid form.

CHAPTER XVI.

Cretaceous System.—Proofs of lapse of time afforded by the oolitic and cretataceous systems.—Persistency of the white chalk over the north of Europe.—Variation of mineral character in Southern Europe—in America.—English cretaceous formations—greensand—its subdivisions—chalk—its subdivisions.—Organic remains—plants few, and exclusively marine—sponges and echinida abundant—hamites—baculites—scaphites—hippurites and nummulites of Southern Europe—two new orders of fishes—reptiles—mosasaurus.—Beds intermediate between the cretaceous and tertiary deposits at Maestricht, Faxoe, and the Eastern Alps.—Oceanic origin of the white chalk—chalk partly composed of microscopic shells—calcareous mud of the Bermudas—precipitation from calcareous and siliceous submarine springs.—Geographical distribution of the cretaceous rocks.—Igneous rocks and disturbances.—Proportions of extinct genera in the different secondary systems.—Mineralization of organic remains.

CRETACEOUS SYSTEM.

Synonyms. Chalk; chalk marl, English authors. *Craie; Craie tufau*, French. *Kneide kreidemergel*, German. *Scaglia*, Italian. Greensand, English authors. *Glauconie crayeuse; Glauconie sableuse*, French. *Chloritische kreide; Planerkalk; Quadersandstein of Pirna*, German.

Proofs of lapse of time afforded by the Oolitic and Cretaceous Systems.

Notwithstanding the great thickness of the wealden, it appears to have been formed in water of little depth; one of the proofs of which is, the repeated occurrence, at various levels, of beds of stone, having a rippled surface, like that observable on sandbanks within the limits of high and low water, or constantly covered by shallow water. This must have been caused by the very gradual submergence of the rock on which the wealden rests; the subsidence being so slow, that it took place no faster than the estuary was filled by the influx of river sediment; and thus we have evidence, in addition to that already adduced, that a great interval elapsed between the conversion of the sea-born strata of the Portland oolite into dry land, and the submergence of the upper part of the wealden beneath the cretaceous ocean. That ocean covered the delta, or estuary, not by a sudden irruption, but by a gradual process, for the upper wealden rocks exhibit a passage into the cretaceous deposits. These are not less than 1000 feet in thickness, are overlaid by a considerable depth of other marine and freshwater strata, which are but the earlier members of the supracretaceous group, containing an entirely different suite of fossils, representing a long zoological epoch, and passing by a gradual change into the present state of nature. Moreover, the entire group of rocks between the Portland oolite and the most recent tertiary bed, constitutes but a small fraction of the fossiliferous series, every member of which is derivative, affords evidence of gradual and successive deposit, and requires time for its formation—time for the abrasion of pre-existing rocks, fragments of which, often containing their peculiar fossils, are found imbedded in newer deposits—time for the consolidation of the sediment of which it was composed—time for the growth of successive generations of plants, zoophytes, and animals which it envelopes—time for the repeated changes of organic types which have taken place, not suddenly, but insensibly, from formation to formation, and from system to system. Who that knows all this, will venture to crowd the long series of events which geology discloses into the brief space during which our race has existed; or will attempt to define the limits of those ages which must have elapsed between the first envelopement of spirifers and zoophytes in the sand and mud which now constitute the solid rocks of Snowdon, and the formation of the first bed of gravel which was deposited after man was placed upon the earth!

Mineral Characters of the Cretaceous System.

The cretaceous group of rocks affords an instance, by no means uncommon in geological nomenclature, of a name founded on mineralogical characters, appropriately applied to a part of the series in the countries where it was first studied, and extended with the advance of our knowledge to rocks of a widely different composition, which, on the evidence of position and organic remains, are proved to have been formed during the same epoch.

The name cretaceous, is derived from *creta*, the Latin for the well-known substance, white chalk, a nearly pure carbonate of lime, in general soft and earthy, but occasionally sufficiently indurated to be used as a building stone. The system may be described as arenaceous and argillaceous in its lower part, calcareous in its upper part.

Persistency of the White chalk over the North of Europe. This, at least, is its character throughout England and a considerable portion of France and Germany; and the white chalk is found, with very slight variations of mineral aspect, but subject to interruptions of continuity over an area above 1100 miles long, extending from the north of Ireland, through England, France, Belgium, Germany, Poland, and Southern Russia, to the Crimea, with a breadth of more than 800 miles, or from the south of Sweden to Bourdeaux.

Variation of Mineral Character in Southern Europe. In the Alps, and on the flanks of the Carpathians, the arenaceous deposits constitute nearly the whole of the mass. In the Pyrenees, the calcareous portions consist of compact crystalline marble, and the arenaceous deposits are represented by shales, grits, and micaceous sandstones, having an aspect nearly resembling that of our carboniferous series, and containing impressions of plants and lignite. On the southern slope of the Alps and in the Apennines, white, greenish, and reddish beds prevail, frequently argillaceous, and not differing very widely from the cretaceous type. In the Morea, compact limestone, granular limestone, jasper, and pudding-stone, with a siliceous base, represent the soft cretaceous rocks of the north of Europe.

America. On the eastern side of the United States, the equivalents of the cretaceous systems of Europe are largely developed in New Jersey, whence they may be traced through the southern states to Florida, and thence to Arkansas, Alabama, and Missouri. In the northern part of this tract, yellow ferruginous and green sands are the prevailing rocks associated with, and at length replaced by limestones, generally compact and shelly, and sometimes approaching a chalky aspect, but affording neither real chalk nor flints.

Subdivisions.

In England, the cretaceous system has been divided into two formations, the greensand and the chalk; in which the following subdivisions have been established.

CHALK FORMATION. Thickness, 600 to 1000 feet.

Upper chalk.
Lower Chalk
Chalk marl.

GREENSAND FORMATION. Thickness, 580 feet.

Upper greensand, (Firestone, Malm rock.
Gault, (Tetsworth clay, Folkestone clay.)
Lower greensand, (Ironsand, Shanklin sand.)

These subdivisions, however, can only be considered local, and are most perfectly exhibited in the south of England; the lower greensand not extending further to the north than Cambridge, nor the upper greensand beyond Lincolnshire. In Yorkshire, the chalk rests on blue or green clay—the Speeton clay of Phillips. Of the chalk formation, the upper part is the most persistent.

The Lower Greensand. This subdivision consists of sand and sandstone, ferruginous in the lower part, green in the upper part, and containing layers of chert, local beds of marl, ochre, and fullers' earth, and cherty, or chalky limestone. Thickness, 30 to 100 feet.

Gault, or Golt. A light blue argillaceous deposit, generally clayey above, and marly below. Thickness, 10 to 180 feet.

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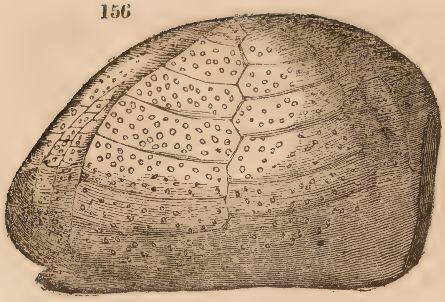

Spatangus coranguinum.

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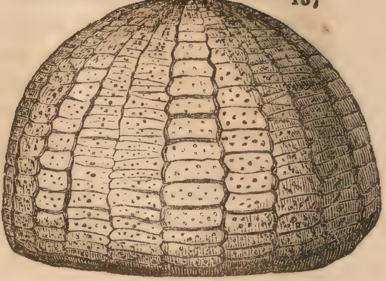

Ananchytes ovatus.

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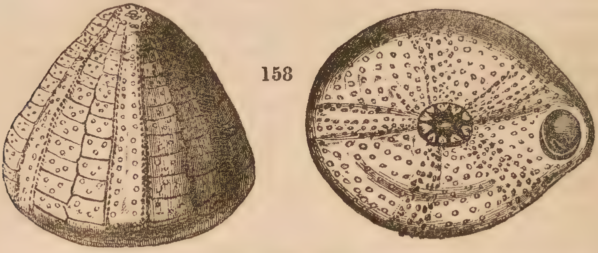

Galerites albogalerus.

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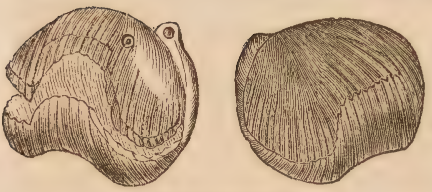

Terebratula plicatilis.

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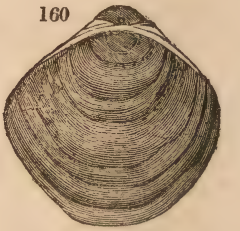

Terebratula carnea.

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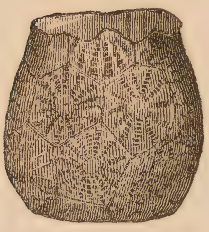

Marsupites ornatus

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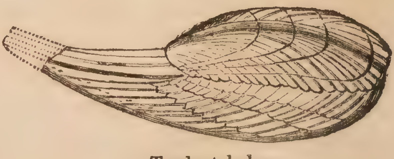

Terebratula lyra.

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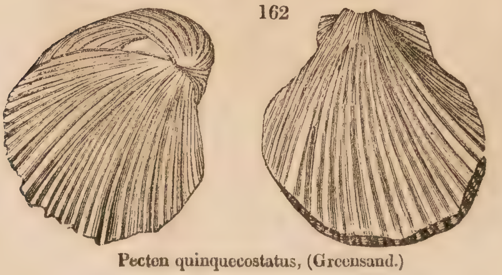

Pecten quinquecostatus, (Greensand.)

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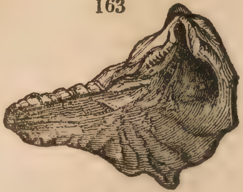

Trigonia aliformis, (Greensand.)

Upper Greensand. Green, gray, or white sands, sometimes passing into cherty, or chalky sandstone, with layers and nodules of chert. The green colour is derived from grains of silicate of iron, which is a variety of chlorite. It is disseminated more or less, through the lower part of the cretaceous system not only in England, but very generally on the continent of Europe, and even in the cretaceous sands of America. Thickness, about 250 feet.

Chalk Formation.

Chalk Marl. An argillaceous form of chalk.

Lower Chalk, harder than the upper chalk, not so white, and containing in general fewer flints. Green grains, and grains of quartz, are sometimes disseminated through it. In Yorkshire and Lincolnshire, and at Hunstanton, in Norfolk, a bed of red chalk, from six to twelve feet thick constitutes the base of this formation.

Upper Chalk, soft and white, with nodules of flint, in layers from four to six feet apart. These layers of flint are frequently almost the only indications of stratification afforded by the mass.

ORGANIC REMAINS.

The organic remains of the cretaceous system are nearly all marine, and afford a group entirely distinct from those of the oolitic rocks below, and the tertiary strata above. The plants are few, and exclusively marine, with the exception of fragments of coniferous wood, which appear to have floated in the sea for a considerable time, as they are perforated by teredines. No land or freshwater shells, and no bones of mammalia, have been met with. Sponges and corals are numerous, particularly the former. Crinoided are rare, being confined almost exclusively to the species Apiocrinus elypticus, and to a genus of crinoidea, named marsupites (155), which was capable of locomotion, being destitute of a column and process of attachment, and probably floated freely, like the medusæ and some zoophytes. Echinida are abundant, the prevailing genera being spatangus (156), ananchytes (157), and galerites (158). Of conchifers, the genera most common and containing the greatest number of species, are terebratula (159—161), pecten, inoceramus, and plagiostoma (162—166). Of cephalopoda, the genera ammonites and belemnites (167), are largely developed, though less so than in the oolitic rocks. The genera hamites (168), baculites (169), scaphites (170), and turrilites (171,) are numerous, and characteristic of this system; a few only being found in the oolites, and none in the tertiary strata.

Hippurite and Nummulite Limestone of Southern Europe. The limestones which, in the countries bordering the Mediteranean, are the equivalents of the cretaceous rocks of the north of Europe, have received the names of hippurite and nummulite limestone, from the abundance of the remains of those two genera contained in them. The shell of the hippurite is unlike that of any genus of mollusc at present existing. It is found in the true chalk of the south of France, and one species has been met with in that of England. The nummulite is a discoid chambered shell, which derives its name from its resemblance to a piece of money. In the north of Europe, it is found abundantly in the tertiary strata (172); as a fossil of the chalk it is confined to the south of Europe. We have in these facts an instance of local contemporaneous differences, analogous to those now existing between the molluscous inhabitants of distant seas, such as the German Ocean and Mediterranean.

The crustaceans of this era are confined to a few remains of astacidæ, a family comprehending the lobster and the crawfish.

Two new Orders of Fishes

The cretaceous epoch is remarkable for a great change in the organization of fishes. During the formation of the older strata, the placid and ganoid orders of Agassiz had exclusively prevailed; in the cretaceous epochs genera of the ctenoid and cycloid orders first appeared. These distinctions are founded on difference in their scaly covering which were accompanied by other peculiarities of organization.

The placoid fishes (from πλαξ *a broad plate*) are characterized by having the skin *irregularly* covered with plates of enamel, sometimes large, sometimes reduced to small points, as in sharks and rays, the former of which afford the well-known substance shagreen. This order comprehends all the cartilaginous fishes of Cuvier, except the sturgeon.

The ganoid fishes (from γανος, *splendour*) are covered *regularly* with angular scales, composed of horny or bony plates, coated externally with a bright enamel. More than five-sixths of the genera belonging to this order are extinct. The bony pike (lepidosteus) and the sturgeon belong to it. (173.)

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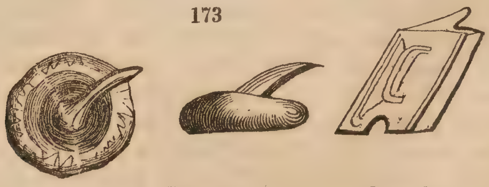

Placoid. Ganoid.

The ctenoid fishes (from κτεις, *a comb*) are characterized by scales jagged or pectinated on the posterior margin, as in the perch.

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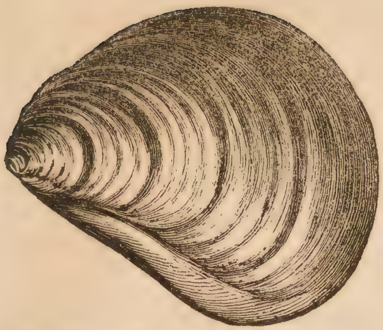

Inoceramus, or Catillus, Cuvieri, (Chalk.)

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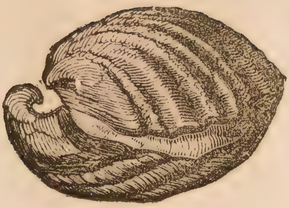

Inoceramus sulcatus.

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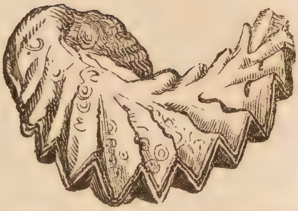

(Ostræa carinata, (Upper Greensand.)

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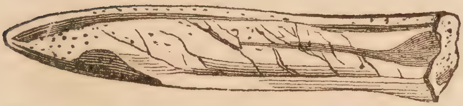

Belemnites mucronatus, (Chalk and Upper Greensand.)

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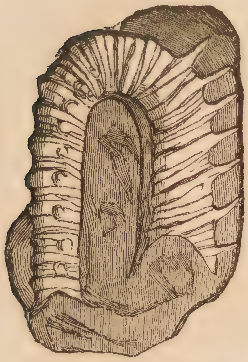

Hamites armatus, (Chalk.)

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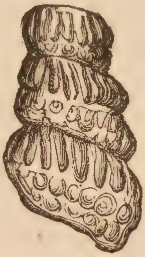

Turrilites costatus, (Chalk and Upper Greensand.

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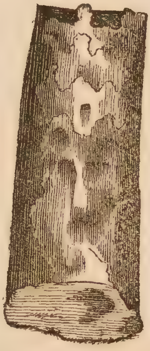

Baculites Faujasii, (Chalk and Upper Greensand.)

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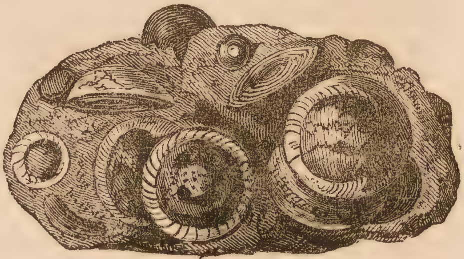

Nummulites elegans, (London Clay.)

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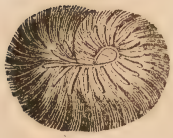
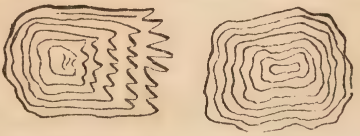


Scaphites obliquus

The cycloid fishes (from κυκλος, *a circle*) have scales smooth and simple on the margin, and often ornamented with various figures on their upper surface. The herring and the salmon are examples. (174.)

174



Ctenoid. Cycloid.

In these two last orders, the scales are composed of laminæ of bone, or horn, and are destitute of enamel. To the ctenoid and cycloid orders, belong three-fourths of the eight thousand known species of living fishes. These orders first appear, as we have already said, during the cretaceous era. Nearly two-thirds of the species of that era belong to extinct genera, and none of them are identical with those of any other system, more ancient or recent.

In the chalk of Sussex, Mr. Mantell has found fossil fishes with the air bladder distended, and containing the contents of the intestinal canal, proving, as in the case of the ichthyosauri of the lias, sudden destruction and rapid envelopement. Certain bodies found in the chalk, and once considered, from their form, to be cones of the larch, have been proved by Dr. Buckland, aided by the analysis of Dr. Prout, to be coprolites or fossil feces of fishes.

Reptiles.

Mosasaurus. Marine cheloniæ occur in the slate of Glaris, in Switzerland, and in other rocks referrible to this era. Only a few remains of ichthyosaurus, once so abundant, are met with in the cretaceous rocks, and that in the lowest portion of them.

Their office appears to have been filled by the mosasaurus, which is characteristic of the cretaceous group. It has been found in the upper chalk of Sussex, in the greensand of Virginia, and in the limestone beds, resting on the upper chalk at Maestricht, of which we shall presently have occasion to speak. By the head and teeth it is allied to the monitor, a small terrestrial lizard seldom exceeding five feet in length. The proportions and organization of other parts justify the conclusion that it was adapted for constant abode in the sea, and must have been as large as a grampus, or about twenty-five feet long.

Though carnivorous, it differed widely in the character of its dentition from the crocodilean type, the teeth having no true roots, and not being hollow as in the crocodiles, but being, when full grown, solid throughout, and united to their socket by a base of bone, as well as by the ossification of the capsule which had furnished the enamel, and which, in this state, formed a circular buttress round the base of the tooth, communicating to it great strength. (175.) The roof of the mouth was also furnished, as in some serpents and fishes, with an apparatus of teeth acting as barbs to prevent the escape of its prey. The vertebræ are all concave in front, convex behind, and fit into each other by a ball and socket joint, allowing of flexion in any direction. They resemble the vertebræ of dolphins, in being destitute, from the centre of the back to the extremity of the tail, of those articular apophyses, or bony processes, which are necessary to support the back of animals which move on the land. The tail, broad and flattened on the sides, and extended vertically like the blade of an oar, was adapted for progressive motion like that of sculling, while for the purpose of descending in search of prey, or rising to the surface to breathe, the animal appears to have been furnished with four paddles, like those of the whale or ichthyosaurus. No bones of mammalia have yet been found in the rocks of this era. Those once referred to cetaceæ, have proved on further examination to have belonged to some unknown saurian.

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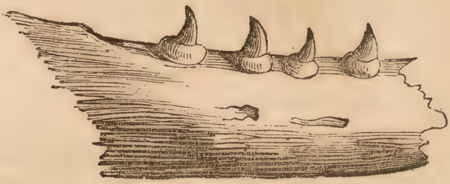

Teeth of Mosasaurus.

Birds.

An important addition to the fauna of this epoch has lately been made, in the humerus of a bird allied to the albatross obtained by Lord Enniskillen, from the chalk of Kent, and in the entire skeleton of a small bird, resembling a swallow, discovered by Professor Agassiz, at Glaris, in the blue slate beds of the lower part of the cretaceous system of the Alps.

Beds intermediate between the Cretaceous and Tertiary Series.

Maestricht and Faxoe. There is in general an entire break between the secondary and tertiary groups, but at St. Peter's Mount, near Maestricht, and at Faxoe, in Denmark, are beds which appear to indicate a passage from the cretaceous to the tertiary systems.

In these localities, chalk fossils of the extinct genera, and species peculiar to the chalk, are associated with turretted univalves of *genera* usually characteristic of tertiary strata, but not identical with tertiary *species*. At Maestricht, this intermixture of fossils is found in a limestone rock, of a coarse sandy texture, superior in position to the upper chalk, and containing siliceous layers not composed of flint, but of chert and calcedony. The organic remains which are considered as indicating a passage from the chalk to the calcaire grossier, consist of ammonites, baculites, hamites, genera not found in any tertiary deposit, and they are mixed with genera of turretted univalves, commonly confined to the tertiary strata. This rock, likewise, contains the remains of mosasaurus, some vertebræ of which have been found in the chalk of England.

In the Isle of Seeland, in Denmark, the white chalk is characterized by the same fossils as the upper chalk of England, and is described by Mr. Lyell as covered, at Faxoe and other places, by a yellowish limestone, consisting chiefly of fragments of coral cemented by a chalky matrix. Like the white chalk it contains flint, but they are more cherty, and in continuous layers. Out of 132 species of shells from this limestone, twenty-six have been ascertained to be identical with chalk species; the rest are distinct from them, and do not agree with any known tertiary shells, though they belong to genera (cypræa, mitra, voluta, fusus, and cerithium), usually deemed peculiar to tertiary formations.*

Eastern Alps. On the flanks of the Eastern Alps, Mr. Murchison and Professor Sedgwick have not only found this mixture of secondary and tertiary genera in strata, resting upon the Alpine limestone (the equivalent of the cretaceous rocks of Northern Europe); but they contend that they are surmounted by higher and conformable strata, containing abundance of tertiary species, and that they thus form a transition group, occurring in a long and unbroken series of formations, interpolated between the oldest tertiaries of the Paris basin and the chalk.

Oceanic Origin of the Cretaceous System.

In describing the wealden group, we have pointed out the proofs of that subsidence which caused the forest of the Portland dirt bed to be covered first by a shallow estuary, and finally by a deep sea. From the destruction of the land thus submerged, we may derive the materials of the lower part of the cretaceous system. Its sands indicate watery agitation, like that of shallow seas near coasts, but the absence of the remains of terrestrial plants, so abundant in the sandstone of the carboniferous formation and of the Yorkshire oolites, precludes the supposition of dry land in the vicinity, and renders it probable that the cretaceous sands were formed, not by the drifting of detritus into the sea by rivers and inundations, but by the action of submarine currents on the submerged land; and the pebbles of the greensand, consisting of quartz, jasper, quartzose sandstone, and flinty slate, with scales of mica and grains of chlorite, indicate the nature of the rocks of which that land was composed. As the subsidence continued, and the depth of the sea increased, the agitation of currents ceased, beds of gravel, sand, and mud, were no longer formed, and the white chalk accumulated over the extensive area already described. Its organic remains, its homogeneous composition, the absence of detritus, with the exception of a few insulated pebbles of quartz and chlorite slate, the presence of which has been explained by Mr. Lyell, on the supposition of their having been floated, attached to sea-weed, all concur in leading to the conclusion that it was formed in the tranquil depths of an open sea. But by what means was it formed? Was it elaborated from the water by organic agency, or was it thrown down as a chemical precipitate from calcareous solutions, existing abundantly in the cretaceous ocean? Dr. Buckland has proposed the hypothesis of a compound precipitate of calcareous and siliceous matter, the organic remains dispersed through the mass constituting nuclei, to which the silex, in separating from the calcareous matter, would have a tendency to attach itself, the distances between the layers of flint being regulated by the intervals of precipitation. Each new mass would thus form, on the floor of the ocean, a pulpy fluid, which did not penetrate the bed on which it rested, because the previous deposit had acquired too great a degree of consolidation to allow of such intermixture.

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* Proceedings of the Geological Society, vol. ii., p. 192.

Chalk, partly composed of microscopic Shells. On the other hand, very strong arguments are adduced in favour of the organic origin of chalk. In the first place, Mr. Lonsdale has discovered that in a mass of this mineral many apparent grains of chalk are in reality microscopic shells and fragments of marine corals, of which he obtained above a thousand from a pound of chalk, and Professor Ehrenberg has detected the siliceous cases of infusoria entering into the composition of flint and tripoli.

Calcareous Mud of the Bermudas. Again, Lieutenant Nelson found, at the bottom of the lagoons of the Bermudas, which are surrounded and inclosed by reefs of coral, a soft white calcareous mud, derived from the decomposition of eschara, flustra, cellepora, and other soft corallines, which mud when dried is undistinguishable from chalk. Similar mud, observed by Mr. Darwin at the bottom of the sea, near coral reefs, in the Pacific, led him to the belief that much of it had resulted from the digestive process of worms and fishes. The latter were seen through the clear water browsing on living corals, and on opening their intestines they were found to contain impure chalk. From the consideration of these facts, Mr. Lyell is of opinion that the white chalk of the north of Europe may have been calcareous mud, derived from the decay of corals growing on reefs and spread far and wide by oceanic currents, however thinly the reefs and islands may have been dispersed through the cretaceous ocean.*

Precipitation from Calcareous Submarine Springs. We must not, however, lose sight of a case, adduced by the same author, of a tertiary freshwater limestone with flints in the Cantal, which is undistinguishable by lithological characters from the true chalk. Into the composition of this freshwater chalk, the mud derived from the composition of coral reefs cannot have entered, and we can have little hesitation in referring the calcareous and siliceous matter contained in it to the waters of springs connected with volcanic action, and charged with lime and silica.† To a combination, therefore, of these two causes we may attribute the formation of the white chalk, vital action elaborating carbonate of lime from the waters of the ocean, and submarine calcareous springs supplying lime to the water. The chalk will thus be partly calcareous mud, derived from the decomposition of organic bodies, and partly a precipitate of carbonate of lime and silica, from which the latter separated in the manner supposed by Dr. Buckland.

Geographical Extent.

The chalk forms an important feature in the geology and scenery of England, from its great extent, from the whiteness of its sea cliffs, and from the smooth and flowing outlines of its hills, covered with short and verdant turf, destitute in a great measure of wood, and marked by winding and inosculating valleys, which appear to have once constituted a system of drainage, even when they are watered by no stream. North of the Humber we have the Wolds of Yorkshire, a range of hills rising from 500 to 800 feet above the sea, and extending nearly fifteen miles inland from Flamborough Head, their western escarpments ranging by Speeton, Knapton, Birdsall, and South Cave, to the Humber, while on the east they sink under the diluvial and alluvial plains of Holderness. On the opposite side of the Humber, the Wolds of Lincolnshire constitute a similar range of hills, with an average breadth of rather more than six miles.

South of the Wash, that great triangular area commences which extends over the eastern and southern counties, bounded on the east and south by the sea, and on the west by a line drawn from Hunstanton Cliffs, in Norfolk, to Abbotsbury, on the coast of Dorsetshire. Within this area the chalk has been denuded over the wealden tract already described, and is partially covered by the two tertiary districts of England.

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* Elements of Geology, p. 321, 326, 330.

† Principles of Geology, vol. iv., 4th edition, p. 172.

The largest and most northern of these tertiary districts is defined on the east by the sea-coast, from near Cromer, in Norfolk, to the southern shore of the estuary of the Thames; on the south by a line drawn from Reculver by Rochester, passing south of Croydon, north of Epsom, and north of Farnham and Kingsclere to Hungerford; while the western boundary ranges, in a northeast direction, by Reading, Amersham, St. Albans, Bury St. Edmunds, Diss, Attleborough, East Dereham, and Norwich, to the sea-coast, near Cromer. The chalk appears in insulated patches about Ipswich and Clare, through the tertiary strata and the diluvium, the boundary between which is not well ascertained. It is also seen beneath these deposits, on the banks of the Thames, near Purfleet, and in the cliffs bordering the coasts of Suffolk and Norfolk. The southern tertiary district is a triangular space, the base of which extends from the banks of the Adder, near Shoreham, to Dorchester, the apex being at Houghton Hill, a little northeast of Salisbury. By these two tertiary tracts, and by the wealden denudation, the great chalk district, which occupies so much of the south and east of England, is divided into several ramifications, the directions of which are defined by the various lines of elevation by which the chalk has been uplifted, either suddenly or gradually, since the commencement of the tertiary era. The principal ramification extends from the northern coast of Norfolk nearly south as far as Newmarket, and thence southwest parallel to the range of the oolite by Cambridge, Baldock, Dunstable, Wendover, and Wantage, to the sources of the Kennet, near Marlborough. Between this point and Farnham, on the north, and a line ranging on the south through Salisbury, Winchester, and Bishop's Waltham, lies the great central expansion of the chalk in Wiltshire and Hampshire, from which two branches extend eastward, under the name of the North and South Downs. The North Downs range from Farnham by Guildford, Dorking, Wrotham, and Canterbury, to Dover. The escarpments of this ridge are to the south, and the dip to the north, and its greatest breadth, (about ten miles) is near the eastern termination, where the strata have the least inclination, while in the steep ridge of the Hog's Back, near Guildford, it diminishes to half a mile. A trough of alluvial deposits divides the chalk of the Isle of Thanet from this main ridge.

The South Downs having their escarpments to the north and the dip of the strata to the south range, with an average breadth of about five miles, from near Petersfield, by Midhurst, Arundel, and Lewes, to the sea at Beachy Head. Another branch runs from Salisbury, in a southwest direction, by Croydon and Dorchester to Abbotsbury, its most western point being near Beaminster. From Abbotsbury, on the Dorsetshire coast, a narrow ridge of cretaceous rocks, in nearly vertical strata, runs eastward through the Isle of Portland to Handfast Point, and reappears in the Isle of Wight, extending from the Needles to Culver Cliffs.

It has been already observed that the greensand formation is wanting in Yorkshire, but it is seen at the base of the escarpments of the chalk in all other parts of England. The greatest height which the chalk attains in this country is at Inkpen Beacon in Wiltshire, 1011 feet above the sea; and there are several hills, both in Yorkshire and the southern counties, which attain an elevation of full 800 feet. In the Alps and Pyrenees cretaceous rocks have been uplifted to the height of 8000 feet above the sea. Scotland and Wales are entirely destitute of the deposits of this system, but in Ireland chalk, harder and more compact than that of England, accompanied by greensand (mulatto), occupies an area of about 800 square miles in the county of Antrim, covered by basalt, but displayed in the sea-cliffs from the entrance of the Foyle to the neighbourhood of Belfast. In the north of France, cretaceous rocks of the English type are largely developed. The white chalk, continued across the Channel, appears on the coast between Calais and the mouth of the Seine in cliffs corresponding to those of Dover and Beachy Head, and sweeps in a broad zone round the tertiary district of the Paris basin, extending on the south as far as the banks of the Loire at Tours, and returning northwards by Auxerre and Troyes. Further south, at the mouth of the Garonne, near Rochelle, is another cretaceous district separated from that of the north of France by an oolitic tract, and covered, between the Garonne and the Pyrenees, by tertiary strata. This southern district, by its mineral characters and organic remains, constitutes the connecting link between the nummulite and hippurite limestone of Southern Europe and the chalk of its northern regions.

The northern portion of the chalk and greensand of the Paris basin, which on the Belgian frontier is in contact with schistose and carboniferous rocks, but elsewhere rests on oolitic strata, is continued through Belgium to Maestricht and Aix-la-Chapelle. On the eastern side of the Rhine, these rocks appear under a more argillaceous form, and extend in a narrow band by Essen to beyond Paderborn. The insulated masses of chalk which are seen in Hanover, Lunenburg, Mecklenburg, Pomerania, in the Isle of Rugen, Jutland, Zealand and the south of Sweden, protruding through the diluvial deposits, render it probable that it forms the basis of a large portion of the plains of Northern Germany. In Scania, sands, containing bituminuos wood associated with cretaceous fossils rest upon the chalk, and lignites of the same age are supposed to occur in Poland, where the cretaceous rocks are extensively developed under the form of a white or light-gray calcareous marl, and of white chalk, identical in character with that of England, and abounding with flints. These rocks are continued in Lithuania and Southern Russia, occupying the country between the Bog and the Dniester, and appearing in detached portions in Moldavia, Podolia, Bessarabia, the borders of the Sea of Azof, and the country of the Don Cossacks.

Igneous Rocks and Dislocations.

In England we have no igneous rocks associated with the deposits of this system, neither do they contain any mineral veins. The whole chalk district of Ireland is overlaid by basalt and greenstone, both amorphous and columnar, in numerous beds alternating with bole or ochre. At Knocklead the entire thickness of the mass is estimated at 1000 feet. At the Giant's Causeway ten beds of basalt and six of ochreous rocks are visible, having an aggregate thickness of 500 feet. These must have originated in currents of submarine lava flowing over the bottom of the ocean after the deposition of the chalk on which they rest, but whether during the tertiary era or before its commencement we have no means of determining. The chalk is also traversed by numerous dikes of basalt and greenstone, which have produced on the sedimentary strata the usual effects near the point of contact. The lias at Portrush and the coal-shales at Fairhead are converted into flinty slate, and the chalk in Rathlin Island, at Glenarm and various other places is changed to crystalline limestone, largely granular near the dike, finally granular at a greater distance, and passing gradually into the unaltered chalk. At Tor Eskert, in Murloch Bay, syenite traverses and covers the chalk. The same rock overlies cretaceous deposits at Weinbohla.

In the Pyrenees they are in contact with granite and become metalliferous. These mountains, with the Northern Appennines, the Carpathians and the ridges of Dalmatia and the Morea, comprising the Pyreneo-apenine system of De Beaumont, have been the theatre of violent and extensive disturbances after the deposition of all the cretaceous rocks in a direction ranging W.N.W. and E.S.E.

In England the cretaceous rocks, as well as the oolitic, appear to have been exempt from any violent movement till the commencement of the tertiary era, when the chalk and supracretaceous deposits of the Isle of Wight were upset, and the anticlinal ridges of Dorsetshire, Hampshire, and Sussex, were produced.

The chalk however affords evidence of a gradual and long-continued process of elevation, to which we may ascribe its wasted surface, the pebbly beds of the early tertiary strata, which rest upon it, the sinuous and inosculating valleys by which it is furrowed, and its numerous escarpments resembling sea-cliffs. Other proofs of the recurring action of gradually elevating forces along the same line, during many geological epochs, are furnished by the narrower limits within which each successive deposit of secondary rocks is confined, from the gradual contraction of the era of the adjoining sea, and by the regularity with which their geographical boundaries follow one another in zones ranging from S.W. to N.E. This process of gradual elevation appears to have been subject to interruption from violent dislocations, such as those by which the carboniferous strata were so generally broken up, and by gradual movements of local depression, evinced by the phenomena of the dirt bed and of the wealden, as well as by the manner in which the chalk both in Yorkshire and Dorsetshire overlaps older deposits; but the result of all these oscillations has been a progressive rise of land, and a progressive addition to the area of England on the south and east, from the period when a few islands of Cambrian and Silurian rocks were first elevated above the waters to that in which the desiccation of the crag converted into dry land part of the littoral deposits of the ancient German Ocean, the counterparts as to mineral character, of those now forming round our shores, and differing from them but slightly in the group of imbedded fossils.

PROPORTIONS OF EXTINCT GENERA IN THE SECONDARY SYSTEM.

With the chalk terminates the long series of secondary strata, in which all the species, and many of the genera and families of organic bodies, are distinct from those now living.

The following estimate has been made by Professor Phillips, of the proportional number of species belonging to extinct genera in the rocks of each system.*

Systems.	Number of Species.	Number belonging to Extinct Genera.	Per Cent.
Cretaceous - - - - -	800	about 300	38
Oolitic, a distinct group of plants	1,300	" 500	38
Poikilitic - - - -	200	" 80	40
Carboniferous; all the terrestrial plants of extinct genera	600	" 150	25
Cambrian and Silurian - -	600	" 400	66

A few only of the same species of shells are found in two systems. No two systems, according to Agassiz, have a single species of fish in common.

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* Consult tables of organic remains in Phillips's Geology, Lardner's Cyclopædia.

Mineralization of Organic Remains.

These organic remains are found in different states, varying in general with the antiquity and mineral character of the deposit in which they occur. There are exceptions, but in general the more recent the rock, the more nearly the fossils approach to their original condition. The greater part of the tertiary strata consist of unconsolidated beds, resembling deposits now in the course of formation, and in these the shells are filled with loose sand or clay, and have merely parted with some of their animal matter. In some cases, they even retain their colour. A large portion of the fragments found in the diluvial gravel of the north-west of England retain their translucency, do not adhere to the tongue, and are in the same condition as shells recently thrown up on the shore. In the London clay, the shells are generally filled with concretionary argillaceous limestone, or with iron pyrites, and the fossils of the lias, and other argillaceous formations of the oolitic series, are in very nearly the same condition. Some of the gryphites and ostrea of those clays even approach more nearly to the ordinary condition of tertiary fossils than do those of the London clay, and, on the other hand, in those tertiary deposits which are partly chemical as well as mechanical, we sometimes find shells as much lapidified as in the secondary rocks. Fossil shells have sometimes undergone decomposition from water percolating the strata, leaving only casts of their internal form, or impressions of their exterior surface. In other cases, the vacant space thus formed between the internal nucleus and external impression has been filled with calcareous spar, pyrites, siliceous matter, or other mineral substance, forming an exact counterpart of the original shell, with its spines, striæ, &c. When the nucleus has consisted of incoherent sand or soluble matter, it has likewise frequently been removed, leaving a hollow shell of flint or calcareous spar. In some specimens of corals and fossil wood, we are not only thus furnished with a cast of the external form, but though all their original calcareous or ligneous substance has vanished, the internal organization is delicately preserved in flint. In fossil wood, so perfect is the preservation of the internal texture, that transverse slices, cut thin enough to transmit light, and magnified about fifty-five times, exhibit the medullary rays and spiral vessels, which distinguish different kinds of wood, and we are thus enabled to determine the natural botanical group to which the plant belonged.

In the chalk, the shells and sponges are generally thus converted into flint, sometimes into iron pyrites. In the limestones of the oolitic and carboniferous systems, they are mineralized by calcareous spar. In the slate rocks, they usually occur as casts or impressions. In the coal measures, bark and ligneous fibre are bituminized, and, as we have before stated, the texture of the different kinds of wood may be detected in thin slices of coal.

The bones of mammalia, found in caverns and tertiary deposits, have in general lost their gelatine, are in a very friable state, and lighter than ordinary bone. In some of the tertiary strata, their vessels have been penetrated by hydrate of iron, which has imparted to them weight and durability and a dark brown tinge. The saurian bones found in the wealden, are usually in the above condition. In the calcareous rocks they are penetrated by carbonate of lime.

Professor Göppert, of Breslau, has recently made some very interesting and successful experiments on the mineralization of organic bodies, by steeping animal and vegetable substances in calcareous, siliceous, and metallic solutions, and has thus established the fact, that, under favourable circumstances, the process may be effected in a much shorter time than was previously supposed. He succeeded in producing, by these experiments, imitative fossils. Layers of soft clay, enclosing recent ferns, were slowly dried in the shade, and then gradually heated till red hot; according to the degree of heat, the plants were reduced to a brown or perfectly carbonized state, in some instances they were black and shiny, closely adhering to the clay. By continuing the red heat till all the vegetable matter was destroyed, an impression of the plant only remained.

Plants were steeped in solutions of sulphate of iron for several days, dried and heated till every trace of organic matter had disappeared, and the oxide of iron thus produced assumed the form of the plant. The same process was applied to thin slices of fir, and oxide of iron was formed, retaining the forms of the vessels by which this tribe of plants is distinguished.

In these experiments, the organic matter was destroyed by heat: but in the process of mineralization, which takes place in the laboratory of nature, it is effected by the slower mode of decomposition, by which the animal or vegetable substance is resolved into its elements, hydrogen, carbon, and oxygen.

These elements, Dr. Turner has observed, are set free in what chemists call a nascent state, a state peculiarly adapting them to enter into new combinations, probably from the extreme minuteness of their constituent atoms; so that if water, holding mineral ingredients in solution, comes in contact with elements in this state, a mutual reaction takes place, solid particles are precipitated and occupy the place of the decomposed organic matter.

We know that the water percolating the crust of the earth holds in solution a small proportion of various earthy and mineral matters, particularly carbonate of lime. With regard to silicification, it may in some cases, particularly in volcanic regions, have been produced by thermal springs, which alone are copiously charged with it, but Dr. Turner has shown that, during the decomposition of felspar, a great quantity of silex is set free, under circumstances which render it soluble in water, both because it is combined with potassa, and because it is in a nascent state, and that thus a large amount of silica may be communicated to the waters of the ocean, which they may again part with during the process of petrifaction.

CHAPTER XVII.

TERTIARY SERIES.

Lithological and zoological characters of the tertiary rocks.—Divisions and nomenclature of Mr. Lyell—eocene—miocene—older and newer pliocene.—Eocene deposits of the Paris basin—fossil contents—subdivision of Cuvier and Brongniart—only locally true.—Lacustrine strata of Auvergne—proofs of slow accumulation.—Tertiary strata resembling secondary rocks.—English eocene deposits—London clay—organic remains—Bagshot sand—freshwater beds of the Isle of Wight.

TERTIARY SERIES.

Synonyms. Superior Order, Conybeare; Supracretaceous Group, De la Beche; Newer and Older Pliocene, Miocene, and Eocene, Lyell. *Tertiärgebilde*, German. *Terrains de Sédiment Supérieur*, French.

The tertiary strata are, on the whole, distinguished from the secondary by their lithological characters; they are, for the most part, less consolidated, consisting of beds of gravel, clay, incoherent sand, or friable sandstone, but this character is not constant; for there are some tertiary strata, particularly of limestone, which are as solid as any of the secondary rocks; and Mr. Lyell has pointed out many instances of tertiary beds possessing the mineral characters which were at one time considered peculiar characteristics of older strata.

The difference between the organic remains of the secondary and tertiary epochs is still more decided. No species of shells is known common to the cretaceous group and the oldest members of the tertiary class.

Even many of the genera are widely different; chambered univalves belonging to cephalopodous molluscs of the genera nautilus, ammonites, scaphites, and baculites, which prevailed in the oolitic and cretaceous systems, are replaced in the tertiary formations by gasteropoda of the genera cypræa, conus, voluta, strombus, murex, fusus, cerithium, mitra, and pleurotoma, genera which, in the existing seas, are the richest in species.

According to the recent researches of M. Agassiz, the fossil fishes of the tertiary era are equally characteristic. A large portion of the genera of the ctenoid and cycloid orders, which commenced in the cretaceous era, expired with it, and new genera of those orders were introduced during the tertiary era, approaching more to the characters of living fishes; but not a single tertiary species has been obtained identical with any now living, and the greater part of the European fishes of that epoch resemble forms now confined to the tropics.

The supracretaceous strata are further distinguished by the absence of those strange and gigantic saurian forms to which we have before alluded, as flourishing during the oolitic period; for the tertiary saurians differed but little from existing crocodiles and alligators.

In the tertiary marine beds the remains of cetacea, or marine mammalia, are first met with, and some of the deposits of the same era abound in the remains of large terrestrial mammalia.

The tertiary strata are likewise distinguished from the secondary by the circumstances under which they appear to have been formed. From the secondary strata occurring in large sheets of rock, continuous over extensive areas, it would appear that while they were deposited a great ocean prevailed over most of the northern hemisphere; but the tertiary strata were formed after the European seas had become divided into gulfs, lagoons, and estuaries, of limited extent, but frequently of great depth. Strata occur, in which land and freshwater shells, drifted wood, and the remains of terrestrial mammalia, are mingled in such a manner as to indicate their formation in estuaries, into which large rivers flowed; and in many cases there are such alternations of marine and fluviatile deposits as to show that the land, during this period, was elevated and submerged more than once. The numerous deposits which contain exclusively terrestrial remains and freshwater shells and fishes, prove that the continents and large islands of the tertiary epoch were extensively covered by lakes.

Thus, by mineral and zoological characters, the tertiary formations are, as a group, well-defined, and easily distinguished from the secondary strata; but the local and independent character of these insulated deposits, renders it extremely difficult to form them into a chronological series; since the cases are rare in which one set of tertiary beds overlaps another, so as to determine their different ages by the evidence of superposition, and their mineral characters are of less value for the discrimination of different members of the system than in the case of the secondary strata. Clay, sand, and gravel are but the detritus of argillaceous, calcareous, and siliceous rocks, more or less finely comminuted; and if we suppose three different contemporaneous seas of limited extent, bounded, one by quartzose or granitic rocks, another by argillaceous schistus, and a third by limestone, it is evident that, on the beds of these seas being laid dry, strata of sand would prevail in that deposit which was bounded by quartzose rocks, clay where the bounding rocks, were argillaceous, and marl where the limestone was sufficiently abundant in the neighbourhood to afford a considerable portion of calcareous matter; or if three rivers charged, one with siliceous, another with calcareous, and a third with argillaceous sediment, should enter the same gulf or inland sea, deposits of these different characters would prevail in the vicinity of the different rivers, and would occasionally alternate with one another, as one river or the other happened to be in flood, when the waters of the others were comparatively low. The whole would produce a complex contemporaneous formation of different mineral characters, in which it would not be very easy to establish any precise order of superposition, almost every different section affording a different series of strata. The nature of the deposits would also be influenced by the velocity of the currents transporting detritus, and the distance to which it was borne. Gravel would be deposited near the shores, and where rapid rivers entered the still water sand would be carried further, and marls composed of the most finely comminuted matter would be transported to the greatest distance, and slowly deposited in the deepest parts. These mechanical deposits would be further modified by the admixture of waters of springs, holding calcareous and siliceous matter in solution, which would precipitate calcareous tuffs and travertins, and beds of siliceous rock. Thus, the mineral characters of the tertiary strata may be relied on as indications of the sources from which their materials were derived, and of the circumstances under which they were formed, but not as indications of the epoch of their formation. It is chiefly, therefore, upon organic remains, that we must rely in determining the relative ages of different members of the tertiary series.

Divisions and Nomenclature of Mr. Lyell.

Regarding testacea as of the most general distribution, and considering the remains of plants and vertebrated animals as consisting of too few species, and confined to too few localities, Mr. Lyell has arranged the tertiary strata under four divisions, according to the proportional quantity of shells of existing species found in them in a fossil state.

To these divisions he has given the names of the pliocene (newer and older), the miocene, and the eocene. These names are formed by compounding the Greek word καινος, *recent*, with πλειων, *more*, or *majority*, μειων, *less*, or *minority*, and εως, *the dawn;* thus indicating that the older tertiary strata only manifest the dawn or commencement of existing races,—that in the middle or pliocene group, these, though more numerous than in the eocene, constitute the minority,—and that in the pliocene, or most modern, they form the majority over extinct species.

The total number of fossil shells known in the tertiary strata are 3036; of these, 777 are found in the pliocene, 1021 in the miocene, and 1238 in the eocene.

The newer pliocene strata contain	90 to 95	per cent. of *recent* species.
The older pliocene	35 to 50	
The miocene	18	
The eocene	3½ to 5	

Eocene Strata.

Tertiary Formations of the Paris Basin. Lacustrine Formations of Auvergne. Basins of London and Hampshire.

The strata of the eocene epoch were the first tertiary deposits that attracted the attention of geologists. Before the strata of the Paris basin had been investigated by Cuvier and Brongniart, the tertiary formations were passed over as mere superficial sand and gravel unworthy of notice, and yet they afford some of the most interesting phenomena of geology; they occupy a large portion of the surface of the present dry land; they throw great light on the distribution of land and water during an epoch which, in geological chronology, is comparatively recent; they furnish us with an assemblage of animals and plants, more varied and extensive than that derived from the secondary formations, and approaching more to the character of those with which we are contemporary; they astonish and delight us by the instances afforded by them of the many curious variations in that great plan of organic mechanism, which has prevailed from the earliest epochs in which we can trace any signs of the existence of animal and vegetable life, up to that creation of which the human race forms a part. By the evidence they afford of the slow progress by which even these comparatively modern deposits have been elaborated, they furnish us with proofs of the long lapse of ages employed in bringing the earth into its present condition; they draw our attention to a state of things approaching that amidst which we ourselves live, and to changes such as are slowly taking place around us; and thus they teach us, in our speculations on the past, to advance from the known to the unknown, and to endeavour to account for ancient changes on the earth's surface as much as possible by the operation of causes now in action, only having recourse to unknown causes for the explanation of residuary phenomena, which it is clear could not have been produced by existing forces acting with existing intensities, however long their action might have been continued.

The formations of the Paris basin consist of several alternations of marine with freshwater strata, from the latter of which have been derived innumerable bones of mammalia of extinct genera and species. For the reconstruction of the skeletons of these unknown animals, we are indebted to the sagacity of Cuvier, and his profound anatomical knowledge. He has described in glowing language the exciting interest experienced by him while occupied in this great work, and has at the same time explained the principles upon which it proceeded. "Placed," he says, "in the midst of a great charnel-house, surrounded by mutilated fragments of many hundred skeletons of more than twenty kinds of animals, piled confusedly around me, the task assigned me was to restore them all to their original position. At the voice of comparative anatomy, every bone, and fragment of a bone, resumed its place. I cannot find words to express the pleasure I experienced in seeing, as I discovered one character, how all the consequences which I had predicted from it were successively confirmed. The feet were found in accordance with the characters announced by the teeth; the teeth in harmony with those indicated beforehand by the feet; the bones of the legs and thighs, and every connecting portion of the extremities, were found set together precisely as I had arranged them before my conjectures were verified by the discovery of the parts entire."*

Fossil Contents.

The result of these labours was the discovery in the Paris basin of nearly fifty extinct species of mammalia, most of them belonging to extinct genera of the order pachydermata, which received the names of palæotherium, anoplotherium, lophiodon, anthracotherium, cheropotamus, and adapis.

These extinct genera approach most nearly to the characters of the tapirs, which inhabit the warm marshy regions of South America and Africa; but they had other points of resemblance, connecting them with the rhinoceros, hippopotamus, hog and horse. The adapis appears to have formed a link between the pachydermata and the insectivorous carnivora. In form it most nearly resembled a hedge-hog, but was three times the size of that animal. The order of carnivora was represented by extinct animals of the genera to which belong the wolf, fox, bat, the coati, a genus now inhabiting the warm region of America, and the genette, which now ranges from the south of Europe to the Cape of Good Hope.

Of the order marsupialia there was a small didelphys, allied to the opossum of North and South America; of the order rodentia, a dormouse and a squirrel; of birds, nine or ten species of the genera, buzzard, owl, quail, woodcock, sea-lark, curlew, and pelican,—all referrible to four of the great orders, accipitres, gallinaceæ, grallæ, aud palmipedes, out of the six into which the existing class of birds is divided. Even the eggs of aquatic birds have been preserved in the lacustrine formation of Auvergne.

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* Ossemens Fossiles, Introduction.

Of reptiles, there were crocodiles and freshwater tortoises, of the genera emys and trionyx; of fishes, Agassiz has determined seven extinct species of extinct genera.

Subdivisions.

The deposits of the Paris basin fill a depression in the chalk about 180 miles long, extending from northeast to southwest, and about ninety miles broad in its widest part. This depression appears to have been a gulf running deeply into the land, and opening towards the north into a sea, which at that epoch must have extended over a considerable portion of the north of Europe. In the course of their researches, Cuvier and Brongniart discovered that the strata above the chalk were not all marine, but that beds containing marine remains alternated with others containing land and freshwater shells, and the bones of terrestrial quadrupeds; and thus they arrived at the same conclusion which had been attained by Smith from the examination of older strata in England, that there are certain fossils peculiar to certain strata. They grouped the beds above the chalk in the following order, beginning with the lowest:

1. First freshwater formation	Plastic clay. Lignite. First sandstone.
2. First marine formation . . .	Calcaire grossier.
3. Second freshwater formation	Siliceous limestone. Gypsum with bones of animals Freshwater marls.
4. Second marine formation .	Gypseous marine marls. Upper marine sands, and Sandstones.
5. Third freshwater formation	Upper freshwater marls, and limestone.

The following are the characters of these formations: *Plastic clay*, so called because used in the potteries, of various colours,—white, gray, yellow, and red,—is of variable thickness, and rests sometimes on the chalk, sometimes on a layer of broken flints, or angular fragments of chalk cemented into a breccia. It contains lignites, amber, and shells, both freshwater and marine.

Calcaire Grossier. A coarse limestone sufficiently hard to be used as a building stone. It is often separated from the plastic clay by a bed of sand. This formation is characterized by the abundance of its fossils, which are chiefly marine. Different groups of fossils are said to prevail in the upper, middle, and lower parts of the bed.

The greater part of the shells, characteristic of the Paris basin, are found in this formation imbedded in a calcareous sand, composed chiefly of broken shells; land, freshwater, and marine shells being mingled together. The marine shells, some of which may have lived on the spot, are characterized by the great proportion of species of cerithium, a genus which inhabits estuaries near the mouths of rivers.

Siliceous Limestone, Calcaire Siliceux. A cellular limestone, sometimes white and soft, sometimes hard and compact, like a precipitate from mineral springs. It is penetrated by silex, infiltrated in every direction. The sides of the cells are coated with mammillary concretions, or small transparent crystals of quartz.

Osseous Gypsum and Marine Marls. The gypseous rocks consist of an alternation of gypsum with white and green calcareous and argillaceous marls. Above this are thick beds of the same kind of marls, containing limneæ and planorbes (freshwater shells), and prostrate trunks of palm trees. The gypseous strata contain the remains of the extinct genera of mammalia before enumerated. Above these, are marls containing marine shells, and among others, a bed of oysters, which are considered to have lived on the spot.

Upper Marine Sands and Sandstones. These are composed of irregular beds of sandstone. In the lower portion, organic remains are very rare, and broken. These are succeeded, in many places, by a limestone, sandstone, or calcareo-siliceous rock, abounding in marine remains of the genera oliva, fusus, cerithium, solarium, melania, pectunculus, crassatella, donax, cytherea, corbula, and ostrea.

Upper Freshwater Formation. Sometimes composed of white friable calcareous marls, at others of different siliceous compounds, some of which are used as millstones. In some places it is destitute of shells, in others, limneæ, planorbes, and helices, abound in it, together with silicified wood, and the seeds of the chara, once considered fossil shells, named gyrogonites. Cuvier and Brongniart supposed that these alternations had been occasioned by repeated irruptions and retreats of the ocean, and that these were the last strata deposited between the chalk and the present state of things; and that the bones of the elephant, rhinoceros, and hippopotamus were only found in superficial gravel, called diluvium, the formation of which was at that time attributed to a general and violent deluge within the historic era. Extensive generalizations from local and insulated facts, are not unfrequent in the history of geology, and instances of them might be pointed out in other sciences, during the progress of their early career. They arise out of our eagerness to arrive at conclusions, and our impatience of unconnected details. We can scarcely be surprised that in the present case they were somewhat hastily adopted; and that, for a time, attempts were made to identify every tertiary formation, wherever found, with some member of the deposits of the Paris basin. These opinions, however, have yielded before a greater accumulation of facts. It now appears that the remains of elephants, which were supposed to be confined to the erratic block group, occur in numerous detached marine and lacustrine deposits, under such circumstances as to indicate gradual accumulation, and they have, in some situations, been found mixed with the remains of the extinct genera of the Paris basin; thus proving the existence of more than one tertiary epoch of long continuance, and indicating a gradual passage from one to the other.

Cuvier's Order of Succession only locally true.

It has been shown, moreover, by M. Constant de Prevost, and other geologists, that not only the theories adopted by Cuvier and Brongniart, to account for the alternations of marine and freshwater strata in the Paris basin, required modification, but that the order of succession established by them for the different deposits, was only locally true, and that the formations 1, 2, 3, viz. the plastic clay, the calcaire grossier, the siliceous limestone and the ossiferous gypsum, instead of being successive deposits, were divisible into four nearly contemporaneous groups. The plastic clay, instead of being confined, as was at first supposed, to the lower part of the formation, alternates with the calcaire grossier; is repeated, with its freshwater shells, in the middle of that limestone, at Veaugirard, Bagneux, and other places, and is to be seen in a recent section near Paris, in the still higher parts of it. The calcaire siliceux, and the calcaire grossier, occupy distinct parts of the basin, the one being most largely developed where the other is of slight thickness. They also alternate with each other towards the centre of the basin. The gypsum, with its associated marls, which was supposed to be entirely subsequent to the calcaire grossier and calcaire siliceux, alternates repeatedly in some places with the calcaire siliceux, and in others with the upper members of the calcaire grossier; and the gypsum and marls attain the greatest thickness where the two other groups are less fully developed. These circumstances seem to imply a gulf open towards the north, and fed by three rivers, one charged with argillaceous sediment, the others holding in solution sulphate and carbonate of lime and silicia. With such solutions, the waters of rivers in volcanic countries are often charged. The marine calcaire grossier is in greatest force towards the north, and the freshwater calcaire siliceux towards the south. Towards the south, we shall presently see there existed during this epoch a chain of lakes connected with extinct volcanos, the drainage of which hydrographical basin might very easily have been into the gulf in which the Parisian strata were deposited; and we shall also see that the basins in which these ancient lakes existed contain calcareous, siliceous, and gypseous strata, precisely similar to the freshwater deposits of the Paris basin. In that basin, the gypseous deposit is most largely developed towards the centre, and M. Prevost, therefore, supposes it to have been precipitated from a river flowing from the east; on which Mr. Lyell observes, that "if the gypsum, and associated white and green marls of Montmartre were derived from a hydrographical basin distinct from that of the southern chain of lakes, this basin must nevertheless have been placed under circumstances extremely similar; for the identity of the rocks of Velay and Auvergne with the freshwater group of Montmartre is such as can scarcely be appreciated by those geologists who have not carefully examined the two countries."*

Though the conditions above supposed, of an estuary fed by several rivers, appear to explain the alternations of the marine and freshwater deposits, called by Cuvier the first and second freshwater and the first marine formations, yet the products of the sea predominate exclusively during the second or upper marine group. It seems, therefore, necessary to have recourse to a subsidence of the land to account for the position of these marine sands, the lower parts of which contain only a few broken shells that appear to have been transported from a distance, and thus indicate the action of water, moving with sufficient velocity to transport sand, and to deposit it over a considerable space; after which, the cause which prevented the envelopement of organic remains ceased, and marine remains were imbedded in considerable quantity. The temporary and alternate prevalence in the estuary of the sea or river, may have been occasioned by slight oscillations of the land; after which, a greater subsidence may have covered with sea a spot previously occupied by fresh water. Calcareous boulders, derived from the calcaire grossier, containing its peculiar fossils, and perforated by boring testacea, have been found in the upper marine sandstone, thus proving, that during the eocene period the calcaire grossier in some part of the basin was exposed to denuding causes. To crown the whole, we have, on these marine deposits, the upper freshwater formation, a deposit of marls and siliceous strata, (such as we shall presently see were formed in some of the lakes we have before alluded to,) containing plants, which exist only on dry land, in fresh water, and in marshy places; and thus we have indications that after the estuary was silted up by the sands of the upper marine formation, a series of pools existed like those which frequently occupy the newest parts of a delta, and which were fed by springs holding siliceous matter in solution.

Lacustrine Deposits of Central France.

We will now proceed to the consideration of that group of lacustrine strata of the eocene epoch lying to the south of the

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* Lyell's Principles of Geology, 4th ed., vol. iv., p. 185.

Paris basin, to which we have just alluded, as exhibiting many points of analogy with that formation, both in mineral composition and organic remains, and as tending to elucidate the circumstances under which it was formed. These deposits are situated in the districts of Auvergne, Velay, and Cantal. The largest of these ancient lacustrine basins is that of Auvergne, about one hundred miles long, and twenty broad, occupying the valley of the Allier above its junction with the Loire.

The boundaries of the ancient lake, which consist of primary rocks, are observable towards the south, east, and west, but not towards the north, where the local disturbances, of which there are abundant evidence in the inclined position of some of the strata, have removed all traces of them. The upper part of the Loire flows through the lacustrine district of Velay, and that of Cantal lies a little to the southwest of Auvergne. The same general characters pervade the freshwater deposits of all these three districts; they may be divided into two groups, the one consisting of gravel and arenaceous strata, the detritus of the neighbouring primary rocks, the other consisting of finely laminated siliceous and calcareous marls, associated with limestone and regular beds of silex, such as would be precipitated from springs charged with carbonate and sulphate of lime and silica.

The coarser detrital matter is confined to the margins of the lakes, not always encircling them in a continuous band, but disposed in the form of those independent deltas, observable where rapid streams enter the water of existing lakes. The finer detrital matters, namely, the siliceous and calcareous marls, occupy the central parts of the basin, having the limestone, gypsum, and siliceous rock subordinate to them, and generally confined to their upper part.

This latter circumstance is of importance, in indicating thermal springs as the source whence these calcareous, siliceous, and gypseous strata were derived, for these deposits are precipitated most abundantly in those regions where volcanic forces are in activity, and these ancient lakes are connected with a system of extinct volcanos, which it is evident had not come into action when the basins began to be filled with sedimentary deposits, because the gravel contains no pebbles of lava, and because, in the districts of Cantal and Velay, no traces of volcanic tuffs are found alternating with the freshwater strata; while in the basin of Auvergne, a few partial alternations only are confined to the upper part of the series.

Not only do the gypseous and siliceous deposits of these lakes agree in mineral character with those of the Paris basin, but they have afforded bones of several mammiferous quadrupeds of the same genera as those by which they are characterized, as also gyragonites, or seed-vessels of the chara, and land and freshwater shells, all of eocene species. Beneath the lavas of some of the extinct volcanos of this district, are several accumulations of alluvium, at different heights above the river, containing bones of the elephant, mastodon, hippopotamus, rhinoceros, tapir, horse, boar, felis, hyæna, beaver, otter, hare, water-rat, deer, and ox, thus proving that volcanic action, which commenced on this spot, during the eocene era, continued through the miocene, and perhaps a later period.

Proofs of Slow Accumulation. These lacustrine deposits afford some curious proofs of the slow and gradual process by which they were accumulated, and of the myriads of insects and molluscs which have contributed their exuviæ to the formation of rocks. The thickness of the green and white marls of Auvergne, is in some places seven hundred feet. They are thinly laminated, the lamination being caused by numerous plates, or scales, of a small freshwater crustacean, called cypris; some of the recent species of which abound in our stagnant pools and ditches. A form of limestone also occurs, called indusial, from its containing immense numbers of the indusiæ, or cases of the larvæ of phryganeæ, insects the living species of which may also be observed in our ponds, and which have the power of fixing small freshwater shells to the outside of their tubular cases. More than a hundred shells of a small species of paludina have been counted on one tube of a large species of phryganea, which abounds in the eocene lakes of Auvergne; and strata of indusial limestone, each six feet thick, which may be traced over a considerable area, are almost wholly composed of these tubes enveloped in travertin, so many as ten or twelve occurring in a cubic inch. In the foliated marls of the Cantal, the laminæ, to the depth of sixty feet, are so thin, that thirty are sometimes contained in the thickness of an inch, in each of which are preserved the flattened stems of the chara, or other plants, and sometimes numbers of small freshwater shells.

Tertiary Strata resembling Secondary Rocks. We must not quit these lacustrine deposits, without observing that they afford several instances of tertiary strata, possessing all those mineral characters which were at one time considered sufficient to identify certain members of the secondary series.

Associated with the marls of Auvergne, and graduating upwards into strata containing eocene fossils, are strata undistinguishable from the new red sandstone of England. Mr. Lyell considers them to have been derived from the detritus of the gneiss and mica schists of the primary strata bounding the tertiary basin, some of which decompose into a very similar soil.

An oolitic limestone occurs in another part of the basin, which bears a close resemblance to the Bath freestone; but the most remarkable instance of the kind, is a freshwater limestone undistinguishable by mineralogical characters from the chalk of England, and containing layers and nodules of flint, which appear to have separated from the matrix after the calcareous and siliceous matter had been blended, the limestone sometimes filling sinuous cavities in the flint, and the flinty nodules being often as irregular in their form as those of the English chalk. This freshwater limestone lies upon the granitic rocks, and as the true chalk sometimes occurs under similar circumstances, there is nothing in the order of superposition which can enable us to decide the epoch of this formation. Its organic remains, however, show that it belongs to the eocene era.

Instead of marine sponges, of the cretaceous epoch, the nodules of flint contain silicified seeds of the chara, a plant that grows at the bottom of freshwater lakes, and instead of echini and marine testacea of the chalk, the freshwater limestone contains lacustrine testacea identical, like the seed-vessels of the chara, with eocene species. These instances are valuable as lessons not to rely too implicitly on lithological characters in determining the age of rocks, and as pointing out thermal springs as one of the sources from which the cretaceous strata may have been derived.

English Eocene Strata.

London Clay.

The English equivalents of the strata of the Paris basin, are the London clay, the Bagshot sands, and the freshwater strata of the Isle of Wight. The term basin, so commonly applied, though seldom with much propriety, to insulated tertiary formations, is particularly inapplicable to those supracretaceous districts, known by the names of the London and Hampshire basins; because there is little doubt that, although now separated by an intervening ridge of chalk, they are portions of a deposit which was once continuous.

The so-called basin of London derives its name from the subsoil of the neighbourhood of the English metropolis being composed of a blue clay, containing marine remains analogous to those of the Paris basin. The London clay, in which term we include the lower part of the deposit, generally separated from it under the name of the plastic clay, occupies a large portion of the county of Suffolk, nearly the whole of Essex, the whole of Middlesex, and portions of the counties of Berks, Surrey, and Kent.

The Hampshire basin extends along the coast, from Brighton on the east to near Poole on the west, its boundary ranging thence inland by Dorchester and Salisbury to Houghton Hill, its extreme point on the north, and thence southeast to its eastern termination at Brighton. It also comprises a large portion of the northern part of the Isle of Wight.

The strata of the Paris basin appear to have been deposited in a depression in the chalk, previously formed by some movement of upheavement. The strata of the same epoch in England are conformable to the chalk, and have partaken of the movements to which it has been subject. Except in Alum Bay, where the London clay has been thrown into a vertical position, they deviate but slightly from the horizontal. From the occurrence of outlying masses of this formation, at a distance from the main body, and at considerable heights on the chalk, Dr. Buckland has concluded, not only that the strata of the London and Hampshire basins were once a continuous deposit, but even that it extended over the plains of Salisbury, Andover, and Basingstoke, and that it has been stripped off the chalk by denudation.

With respect to mineral character, the London clay may be described as a formation consisting of a series of clays above, and of sands and of shingle below. This formation has been subdivided into the London clay and the plastic clay, the former name being applied to the upper parts of the series, the latter to the lower. This subdivision arose out of the opinion which prevailed after the description of the Parisian supracretaceous strata by Cuvier and Brongniart, that these strata formed the type to which all tertiary formations must be referred.

The attempt to establish an identity between the details of two contiguous groups like these, possessing the same zoological character, was more excusable than in some other cases where the intervening distances were greater and the anologies more remote. This subdivision of the London clay, however, is perfectly arbitrary; but if the subdivision had been necessary, nothing could be more unhappy than the name of *plastic clay,* applied to the lower part of the series, which consists, almost wholly, of beds of various colours and of shingle, the clay only occurring in layers subordinate to the shingly and sandy masses.

The upper portion of the London clay is a tough bluish or blackish clay, sometimes slightly calcareous, rarely passing into a calcareous or siliceous sandstone, as at Bognor rocks, or into a stratified limestone, as in the cliff at Harwich. Concretions of argillaceous limestone, of an ovate form, traversed by intersecting fissures filled with calcareous spar, and thence called septaria, occur in the clay, both as detached nodules and in layers. Crystals of selenite are found in it, and most of its fossils are mineralized by sulphuret of iron.

Organic Remains of the London Clay. This deposit contains remains of tortoises, crocodiles, crabs, fishes, and marine shells in great abundance, consisting chiefly of the genera voluta, rostellaria, fusus, cassidaria, ancellaria, buccinum, pleurotoma, cypræa, conus, cerithium, terebellum, and turritella, all existing genera of univalves, though most of the species are extinct (176—181). Out of 400 marine shells, from the London clay, recently examined by Mr. Lyell and Mr. G. Sowerby, scarcely two per cent. proved identical with living species. A nautilus (182), resembling nautilus pompilius of the Indian seas, is also common, but no ammonites and belemnites, so abundant in the chalk. Terebratulæ and echinida are rare, as are likewise zoophyta. Considerable portions of the trunks of trees are found in it, often perforated by teredines, which shows that they must have been floating some time in the sea, but land must have existed at no great distance to have supplied the fruits of a tropical aspect allied to cocoa-nuts and other palms, which are found in such abundance in the cliffs of the Isle of Sheppey. The remains of crocodiles and turtles also prove the existence of some neighbouring continent or island, to which these oviparous reptiles could have resorted for the purpose of depositing their eggs. Among the vegetable remains of this formation must be enumerated copal or fossil resin, sometimes met with in small nodules. Organic remains are rare in the lower part of the series: when they occur, they consist chiefly of the genera murex, cerithium, turritella, and ostrea, with a slight admixture of the fluviatile genera planorbis and cyclas. Seams of lignite occasionally occur.

Bones of mammalia were till lately unknown in the London clay, but some remains found in that deposit near Woodbridge, in Suffolk, have been identified by Mr. Owen as the tooth and part of the jaw of a monkey, part of the jaw of an opossum, and the teeth of a bat. He has also described the skull of a new and extinct genus of pachyderm, from the London clay of Herne Bay, intermediate in character between the hyrax, hog, and chæropotamus, to which he has given the name of hyracotherium.

The same eminent anatomist has detected among the fossils of the London clay, from the Isle of Sheppey, in the Hunterian collection of the College of Surgeons, and in the cabinets of Mr. Bowerbank, the sternum and vertebræ of a bird allied to the vultures, but of a smaller size than any living species, and the vertebræ and ribs of a serpent allied to the bones and pythons, which must have been ten or eleven feet long. "Serpents of similar dimensions, Mr. Owen observes, exist in the present day only in tropical regions, and their food consists principally of warm-blooded animals, and he therefore declares, that had no evidence been obtained of birds or mammalia in the London clay, he would have felt persuaded that they must have coexisted with these fossil serpents."*

These remains, therefore, of the inhabitants of the land, monkeys, large serpents, and vultures, corroborate the inferences as to the high temperature of the northern regions of Europe during the eocene epoch, which had previously been founded on the

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* Proceedings of Geological Society, vol. iii., p. 161.

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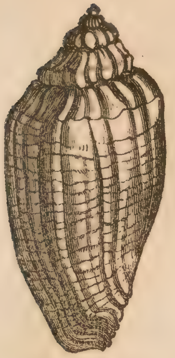
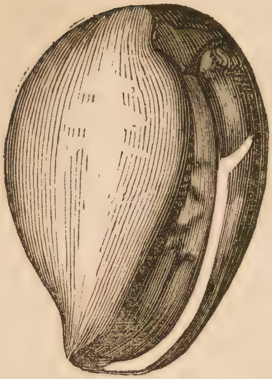


Voluta ambigua,
(London clay.)

177



Cypræa oviformis,
(London clay.)

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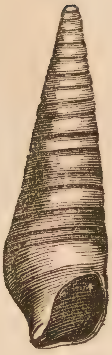

Cerithium intermedium,
(London clay.)

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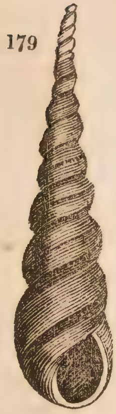

Turritella edita,
(London clay.)

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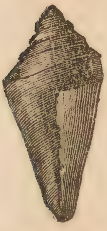

Conus concinnus,
(London clay.)

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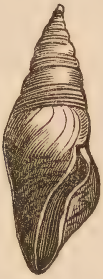

Pleurotoma prisca,
(London clay.)

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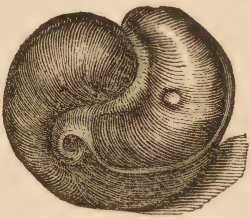

Nautilus imperialis,
(London clay.)

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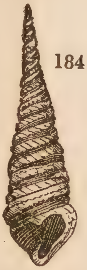

Potamides cinctus.

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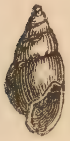

Paludina elongata.

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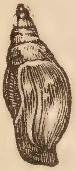

Melanopsis carinata.

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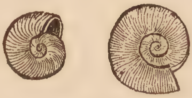

Planorbis lens.

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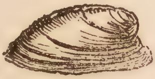
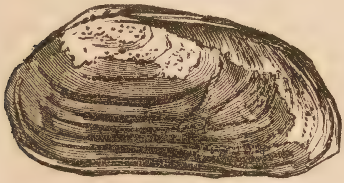


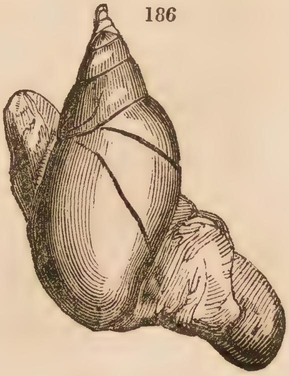
Ancylus elegans.

185



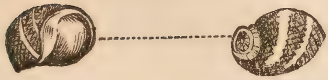
Unio Solandri.

186



Limnea fusiformis.

190



Neritina concava.

character of its vegetation, and on the crocodiles, turtles, saw-fishes, chimæras, sharks, and nautili, which swarmed in its waters.

The thickness of the London clay, as ascertained by numerous wells and artesian borings, is very variable, and is much less on the eastern than on the western side of London. At Bromley, it is 44 feet; at Tottenham, 77; in St. James's Street, 235; at Wimbledon, 530 and more; at High Beach, in Essex, 700 (estimated); at Portsmouth, 102. The greatest height it attains above the sea is at High Beach, 759 feet.*

Bagshot Sands.

These rest on the London clay, and consist of ochreous sand, alternating with foliated green clay, green sand, and sulphur-yellow, white and pinkish foliated marls. Organic remains are rare, but a few imperfect shells have been found in the marls, of the genera trochus, pecten, and crassatella, which appear to belong to eocene species of the Paris basin. The remains of fishes indicative of the same era, have also been found in this formation. It occupies the surface of Bagshot, Frimby, and Purbright heaths; St. Anne's and Shrubs' hills, west of Chertsey, St. George's Hill, near Weybridge, Chobham Ridges, and Romping Downs, north of the Hog's-back in Surrey, and the Hampstead and Highgate hills in Middlesex. The greatest elevation above the sea is 463 feet.

Freshwater Formations of the Isle of Wight.

These beds were discovered by Mr. Webster, soon after the publication of the description of the formations of Paris by Cuvier and Brongniart. He divided the formation into a lower and an upper freshwater deposit, separated by a bed containing marine remains; and he gave it the name of the upper marine, considering it the equivalent of the formation of the Paris basin, so named by those authors.

The existence of this marine bed was afterwards questioned; but subsequent observations by Professor Sedgwick and Mr. Lyell have established an intercalation of strata, containing a mixture of marine and freshwater shells between two beds, the organic remains of which appear to have been deposited tranquilly on the spot. The series is exposed in the face of the cliff at Headen Hill, the total thickness of all the strata amounting to about 400 feet, with about thirty-six feet of the marine formation appearing midway in the cliff. The lower marine is worked in the quarries at Binstead, near Ryde. At Headen, the lower freshwater formation consists of sand, calcareous and argillaceous marls, containing shells of the genera paludina, potamides, melania, cyclas, unio, planorbis, and limnea, all inhabitants of freshwater (183—187). At Binstead, it consists of limestone, composed of fragments of freshwater shells, siliceous limestone, and calcareous marls. At the quarries of this place, in the marls alternating with the limestone beds, a tooth of an anoplotherium, and two teeth of a palæotherium, have been found, accompanied by other rolled and broken bones of pachydermata, and the jaw of a new species of ruminantia, allied to the genus moschus, or musk deer.

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* Conybeare and Phillips, Outlines.

The marine formation at Headen is about thirty-six feet thick, and consists principally of greenish marl. The shells, according to Professor Sedgwick, are chiefly of the marine genera murex, buccinum, natica, venus, nucula, and corbula, mixed with a few of the freshwater genera cyclas, potamides, melanopsis, and neritina (188, 190).

The upper freshwater formation is composed of a yellowish-white marl, enclosing masses which are more indurated, and containing freshwater shells of the genera limnea, planorbis, and helix, together with the seeds of chara and the remains of coleopterous insects. This freshwater formation is surmounted by a mass of transported gravel.

The lower freshwater formation, from the phenomena exhibited at Headen Hill, appears to have been deposited tranquilly in fresh water. The mixture of land, marine, and freshwater shells in the marine bed, implies deposit in an estuary; but to produce that estuary, there must have been a change of level.

The strata at Hordwell Cliff, on the coast of Hampshire, consisting of alternations of clays and gravels, some of a bluish-green colour, are surmounted, like those of Headen Hill, by a mass of transported gravel. They have afforded scales of a tortoise, seed-vessels of the chara, teeth of a crocodile, and scales of fishes, together with shells of the genera melania, melanopsis, planorbis, limnea, potamides, neritina, ancylus (189), unio, mya, and cyclas.

From the vertical position of the strata of the London clay in Alum Bay, and from the horizontal position of the freshwater strata in other parts of the island, Mr. Webster inferred that the latter were not deposited till after the upheavement of the former; but Professor Sedgwick has shown that these appearances are deceptive, arising from the local nature of the disturbances at Alum Bay; that the freshwater beds are there vertical, as well as the London clay and the chalk; and that wherever they are horizontal, the chalk is horizontal also: so that the freshwater beds were deposited before the chalk was upheaved, and have partaken of its movements.

CHAPTER XVIII.

TERTIARY SERIES,—CONTINUED.

Miocene Strata.—Faluns of the Loire—mammalian remains.—Basin of the Gironde—Basins of Vienna and Lower Styria—Volhynia and Podolia—of the Rhine.—Dinotherium.—Older Pliocene Strata.—Difference of opinion among eminent conchologists respecting the shells of the crag—difficulty of distinguishing shells so closely allied as tertiary and living species.—The coralline and red crag, miocene.—The Norwich crag, older pliocene.—Strata of Bridlington.—Subapennine marls.—Tertiaries of the Maritime Alps—Spain and the Morea.—Newer Pliocene.—Sicilian tertiaries.—Extra European tertiaries.—North America—South America—metamorphic and metalliferous tertiary beds of the Andes—extinct gigantic mammalia—toxodon—megatherium—macraukenia.—Indian tertiaries—extinct mammalia of the Sewâlik Hills—remains of monkeys—sivatherium—anoplotherium.—Resemblance between the tertiary animals of India and France.

MIOCENE STRATA.

To this epoch belong the faluns of the Loire; the basin of the Gironde, or deposits of Bourdeaux and Dax; the tertiary strata of Montpellier; those of the hills of Mont Ferrat and the Superga; the molasse of Switzerland; the deposits of Lower Styria and Vienna, in the basin of the Danube; the deposits of Volhynia and Podolia; the basin of the Rhine, near Mayence; and perhaps the lacustrine strata of Epplesheim, in Hesse Darmstadt, and Georgesgemund, in Bavaria. To these Mr. Lyell now adds part of the English crag (the coralline and the red crag), the whole of which he formerly referred to the older pliocene era.

Faluns of the Loire. This deposit is of slight thickness, resembling the English red crag in mineral composition. It contains marine shells mixed with mammalian remains, some of which are encrusted with flustræ and balani, and thus appears to have been formed near the shore.

M. Desnoyers referred it to the age of the English crag, because of the similarity of its lithological characters, and because it rests on the upper lacustrine formations of the Paris basin, which are continuous over a platform between the Seine and the Loire, in the same manner that the crag rests on the London clay. Mr. Lyell and Mr. Deshayes, however, on account of the proportional quantity of recent species obtained from it, considered it, till lately, intermediate in age between the crag and the deposits of the Paris basin. The present state of this question will be noticed in the sequel.

Mammalian Remains. In some strata of the same age as the faluns, which occur a little west of Orleans, remains of palæotherium magnum (a species of the Paris basin) have been found, accompanied by mastodon angustidens, hippopotamus major, hippopotamus minatus, tapir gigas, a small species of anthracotherium, sus, equus (a small species), cervus, and an undetermined species of rodentia; and similar mixtures of the extinct genera of the lacustrine eocene mammalia, with the earliest forms of existing genera, have been found at Georgesgemund, in Bavaria, and at Epplesheim, near Hesse Darmstadt.

Basin of the Gironde, District of Bourdeaux and Dax.

There is a great extent of tertiary strata between the Gironde and the Pyrenees. They are variable in their mineral character, but admit of an arrangement into four groups, their united thickness being, in some instances, very considerable, while in others the secondary rocks are scarcely concealed by a thin covering of tertiary strata.

These groups in the neighbourhood of Dax are in the descending order:—1. Siliceous sand, without shells; 2. Gravel; 3. Sand and marl, with shells; 4. Blue marl, with shells. The shells are of the same zoological character as those of the basin of the Loire. There is often an intermixture of fluviatile shells with the marine, indicating an estuary deposit.

At Saucats, near Bourdeaux, is a freshwater limestone, of considerable thickness, perforated on its upper surface by marine shells, chiefly of extinct species: thus affording evidence that the spot has been occupied alternately by salt and fresh water.

The tertiary series of the basin of the Gironde rest in general on secondary rocks; but between Blaye and La Roche, they are stated by Mr. Lyell to be superimposed on limestone, from 100 to 200 feet thick, resembling the calcaire grossier of the Paris basin, and containing many species identical with the shells of that formation.

Montpellier. These deposits are classed by Mr. Lyell with those of the miocene epoch, because they contain many of the Bordeaux and Dax species of shells; although the catalogue of M. Marcel de Serres enumerates many pliocene species. The mammalian remains appear to be those of the miocene era,—mastodon angustidens, rhinoceros leptorhinus, a tapir, a palæotherium, and an anthracotherium.

Piedmont. The hill of Superga, near Turin, and the chain of

Mont Ferrat, in the basin of the Bormida, consists of highly-inclined strata of greensand and marl, coarse conglomerate forming the lower part of the mass. Shells referrible to the miocene era occur in the greensand. Nearly horizontal marls, containing shells of the older pliocene strata, are seen in various places near Turin. The country has not yet been sufficiently examined to obtain sections illustrative of the position of miocene and older pliocene strata, but it has been ascertained that the highly-inclined greensand, which is in contact with the primary strata, is the oldest part of the series.

Molasse of Switzerland. At the northern base of the Alps, on the side of Savoy, and throughout the lower part of Switzerland, a soft green sandstone occurs, called "molasse," much resembling some of the beds of the basin of the Bormida, and associated, like them, with marl and conglomerates. It contains but few shells, but some found near Luzerne are referred to this epoch.

Basins of Vienna and Lower Styria.

Of all the tertiary groups of Europe, this is, perhaps the most important in point of thickness and geographical extent, though others have obtained more celebrity, from the nature of their organic contents, and from some of the most interesting investigations of modern geology being connected with them. The Styrian beds, described by Mr. Murchison and Professor Sedgwick, exhibit nearly the same phenomena as those of Vienna, and are divisible into three groups, in position nearly horizontal, but having a slight dip towards the east. They appear to have been formed in an inland sea, which once filled the basin of Hungary, and extended to the foot of the eastern termination of the Alps; the Vienna strata having been formed in another bay of the same sea, separated by a great promontory connected with the central ridge of the Alps. The Styrian tertiary strata, near their western termination among the older and more elevated formations, fill an irregular trough-shaped depression, through which the waters of the Mur, the Draab, and the Drave, make their way to the Lower Danube. From this region they gradually expand into the plains of Hungary.

We have already said that they may be divided into three groups, the first occupying the broken region extending from the neighbourhood of Eibeswald, and the eastern skirts of the Schwanberg Alp, to the banks of the Mur; it consists of alternating beds of shale and sandstone, with marl and sand, some of the marls containing many marine shells. Near the protuberances of secondary rocks, are masses of conglomerate, containing rounded siliceous pebbles, and resembling the shingle of a beach. This group is referred, by Professor Sedgwick and Mr. Murchison, to the age of the Paris basin; but Mr. Lyell contends that though some of the shells mentioned by them are common to the Paris basin, such a coincidence holds true with regard to all the miocene formations of Europe, and that associated with them, are some characteristic miocene fossils.

The second principal group is finely exposed in the escarpments of Wildon, and in the hills of Ehrenhausen, on the right bank of the Mur. It is characterized by coralline and concretionary limestone, of a yellowish-white colour. The upper beds of this group occupy a considerable portion of the hilly region on the south side of the Mur, stretching nearly east and west. They consist of marls, sometimes so calcareous as to pass into irregular concretionary masses of white limestone, of beds of shale, and of sand and sandstone, occasionally so coarse as almost to assume the form of a conglomerate. The coralline limestone is in some places four hundred feet thick, and affords an instance of a tertiary coralline limestone more largely developed than the secondary coral rag of England. This group is unanimously admitted to belong to the miocene epoch.

The third group consists of marl and sandstone, abounds in fossils, and contains beds of coarse calcareous sandstone. The authors include in it the yellowish micaceous sands with bands of sandy marl, and occasionally beds of small pebbles, which occupy a large portion of the surface of the country near the frontiers of Styria and Hungary. They contain the bones of several species of mammalia. Professor Sedgwick and Mr. Murchison class this group with the younger deposits of the Subapennine regions, that is, with the pliocene era. Mr. Lyell is of opinion, that its fossils do not depart so widely from the miocene type as to authorize their separation.

The deposits of the Vienna basin are in the same horizontal or slightly inclined position, and exhibit very nearly the same phenomena as those of Lower Styria.

Owing to their slight inclination, the lowest groups are very little known, having only been reached by boring for water, and other artificial excavations. Professor Sedgwick and Mr. Murchison give the following synopsis of the successive deposits in the neighbourhood of Vienna, on the authority of M. Partsch, some of the facts having been verified by their own observations. The section is in the descending order:*

	Feet.
1. Alluvial loam, called Loss, with terrestrial shells of existing species mixed with bones of extinct elephants; average thickness 60 feet, in some places much more	60

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* Transactions of the Geological Society, New Series, vol. iii., part 2, p. 403.

2.	Gravel and sand, with subordinate concretionary calcareous masses, sometimes oolitic. It contains the bones of mastodon, anthracotherium, tapir, &c.	70
3.	Freshwater limestone, only in patches, containing planorbes and helices	140
4.	Great white coralline limestone, containing large pectens and echini, also bones of the tapir, mastodon, stag, and other mammalia	150
5.	Coarse calcareous conglomerate breccia, and calcareous grit, forming the base of the white coralline limestone of the Leitha Gebirge	200
6.	Superior blue marl (Tegel) with a profusion of fossils	40
7.	Yellow sand, with calcareous grits, and many fossils. Cerithium pictum, and two or three species of ostrea, abound in it	120
8.	Inferior blue marl (Tegel), only known by borings, and some partial excavations; fossils, therefore, little known	300
9.	White sands, &c., reached only by boring; thickness, therefore, entirely unknown.	
		1080

Volhynia and Podolia. In this district, bounded by Gallicia on the west, and the Ukraine on the east, and comprising parts of the basins of the Don and Dniester, there is a great accumulation of sand, sandstone, clay, coarse limestone, and a white oolitic limestone, the last of considerable thickness. The marine shells derived from these deposits have been pronounced by Deshayes to belong to the miocene era.

Mayence. The tertiary strata of Mayence extend along the left bank of the Rhine, from Mayence to the neighbourhood of Manheim and recur near Frankfort. From the abundance of shells of the genera cerithium, and the quantities of land shells contained in them, they appear to have been formed in an estuary fed by rivers. The sandy beds of Epplesheim, in which the remains of dinotherium are found, have been already mentioned as probably belonging to the miocene era.

Dinotherium. In this latter locality occurs the dinotherium, the largest of known terrestrial mammalia. It appears to hold an intermediate place between the tapirs and the mastodon. The scapula, or shoulder-blade, resembles more nearly that of the mole than any other animal, and implies an adaptation of the fore-leg to the purpose of digging, an inference which is confirmed by the singular structure of the lower jaw. In the character of its molar teeth, it is nearly allied to the tapirs, but it differs from them, and indeed from all other known quadrupeds, in having two great tusks at the anterior extremity of the lower jaw, curved downwards, like those in the upper jaw of the walrus.

From the inconvenience so bulky an animal, possessing jaws four feet long, armed with such enormous tusks, must have experienced on the dry land, and from the aquatic habits of the tapirs, to which it appears allied, Dr. Buckland supposes that it lived chiefly in freshwater lakes; and that the tusks were employed in grubbing up the roots of large aquatic vegetables from the bottom, in which service they would combine the mechanical powers of the pickaxe with those of the horsehoe, the great weight of the head assisting the operation; he also considers that these tusks might also have been applied to moor the head of the animal to the bank, as it slept submerged, with the nostrils only above the water; and that they might likewise have been used, like those of the walrus, for the purpose of dragging the body out of the water, and as weapons of defence.

From its near approximation to the living tapir he inferred that it was furnished with a proboscis, by means of which it conveyed to its mouth the vegetables raked up from the bottom by its tusks and claws; and from an ungual bone found with some other remains of dinotherium, having a remarkable bifurcation, not known in any other quadruped except the pangolins, he inferred that it was furnished with a claw possessing peculiar advantages for scraping and digging, and thus indicating functions concurrent with those of the tusks and scapula.

Since the publication of the first edition of the *Bridgewater Treatise*, in which these views were advanced, a nearly entire head has been found by Professor Kaup: the width of the anterior portion of the skull, and the deep depression there visible, seem favourable to the supposition of its having been furnished with a proboscis; and Professor Kaup and Dr. Klipstein, who have described and figured the skull, consider Dr. Buckland's conjectures as to the aquatic habits of the animal, confirmed by the approximation in the form of the occipital bone to the occiput of cetacea, the dinotherium in this structure affording new and important links between the cetacea and pachydermata. M. de Blainville, and some other French naturalists, even consider it to have belonged to the cetaceous order, and the family of the dugongs and lamantins.

Older Pliocene Strata.

Part of the English crag, the Subapennine sands and marls of Tuscany and Northern Italy, also the beds of marl and gravel at the foot of the Maratime Alps near Genoa, the tertiary strata at the eastern extremity of the Pyrenees, in the south of France, and at Malaga and Grenada in Spain, and the tertiaries of the Morea, are all referred to this epoch by M. Deshayes and Mr. Lyell, because they contain the same proportion of existing species of shells. The European mammalian remains of the pliocene era consist of existing genera, but of species extinct, or no longer inhabitants of Europe, such as the elephant, hippopotamus, rhinoceros, and mastodon, an extinct genus allied to the elephant. Dr. Buckland says that this is the oldest formation in which ruminantia,—oxen, and deer, are abundantly found, and that it is also distinguished by the increased abundance of rodentia and carnivora. Those extinct genera of pachydermata which flourished during the eocene period, are not found in the pliocene strata of Europe, while mixtures of the eocene and pliocene mammalia occur, as has been already stated, in strata of the miocene era.

The seas of the pliocene era, as well as of the miocene, were inhabited by marine mammalia, consisting of whales, dolphins, seals, the walrus, and the lamantin, or manati, the existing species of which last genus are confined to the tropics.

The Crag.

The only English marine tertiary formation of the miocene and older pliocene epochs is called the crag, a provincial name for gravel in the counties of Norfolk, Suffolk, and Essex, where it occupies the low grounds along the coast, resting sometimes on the chalk, sometimes on the London clay. Three regular marine formations, as well as the diluvial drift, were until lately confounded together under this name. Mr. Charlesworth was the first geologist who divided the crag of Suffolk into two formations, the uppermost characterized by its ferruginous colour, the lower

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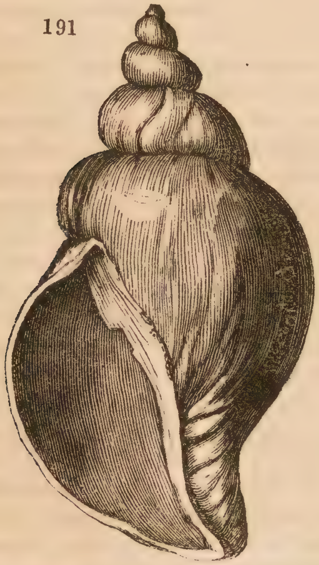
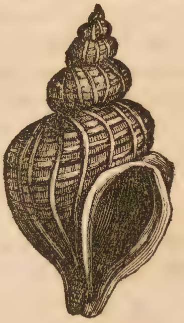


Fusus contrarius, (Red Crag.)

192



Murex alveolatus,
(Red Crag.)

by the presence of corals; and he proposed for them names of the coralline and red crag. He also intimated that the crag of Norwich was more recent than either of them. The red and coralline crag are best seen at Ramsholt, on the eastern bank of the Deben, at Tattingstone, between the Orwell and Stour, Sudbourn Park, twenty miles to the east of Tattingstone, and Orford.

The red crag varies in thickness from four to nine feet, the coralline crag from seven to twelve. The latter deposit consists of white calcareous sand, and contains many shells which do not appear to have been rolled, and the species often occur in groups. The corals are most abundant at Orford and Sudbourn. From the two deposits have been obtained the following species:—annulata, 13; conchifera, 189; cirripeda, 11; mollusca, 257. The mollusca include 50 species of minute cephalopoda. Of the above species, 80 are considered peculiar to the red crag, 280 to the coralline crag, and the remaining 150 are common to the two deposits. The fusus contrarius (191), and the buccina and murices (192), so abundant in the red crag, are wanting in the coralline crag. The former contains teeth of fishes, in the latter they are rare. The remains of mammalia appear confined to the upper beds. Mr. Charlesworth concludes that these deposits were formed under different conditions, and at different epochs. In commenting on these facts, in his address from the chair of the Geological Society, in 1835, Mr. Lyell admitted the former conclusion, but denied the latter.

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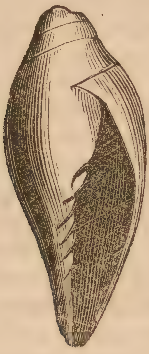
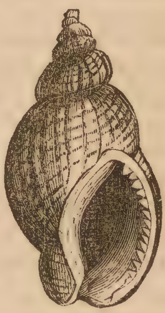


Voluta Lamberti.

194



Nassa reticosa.

Discordant Opinions respecting the Shells of the Crag.

Referring to an opinion of Mr. Charlesworth, that of the 150 species common to the two deposits, many may have belonged to the lower bed and been washed into the newer one, Mr. Lyell observed, "Such accidental mixtures have doubtless occurred, and they have been occasionally remarked by geologists in other places, under similar circumstances, but I continue to believe that these upper and lower divisions of the crag should be referred to the same geological epoch. The determination of that period, or of the exact place which the crag should occupy in the chronological series of the European strata, is a more difficult question. When I first submitted 111 species of crag shells to the examination of M. Deshayes, he was of opinion that 66 of them were extinct, and that the others belonged to recent species now inhabitants of the German Ocean. I lately laid before him 60 species from the coralline crag with which Mr. Charlesworth has favoured me, and he was still of opinion that the proportion of recent species was equally great.

"But I should add, that the suites of individuals of each species were not so full and complete as might have been desired, to enable these identifications to be placed beyond all doubt. Dr. Beck has lately seen 260 species of crag shells in Mr. Charlesworth's cabinet in London, and informs me, that, although a large proportion of the species approach very near to others which now live in our northern seas, he regards them as almost all of distinct species, and unknown as living. Both he and M. Deshayes have declared the shells to be those of a northern climate, and, according to Dr. Beck, the climate may even have resembled that of our arctic regions.

"In regard to the discordance in the results at which these eminent conchologists have arrived, it may arise not only from the unequal opportunities which they have enjoyed of examining the necessary data, but also, in part, from the different estimate which they have formed of the amount of variation necessary to constitute a distinct species. One example will sufficiently illustrate my meaning. Those naturalists who agree with M. Deshayes, in referring all the living varietes of lucina divaricata brought from different countries to one and the same species, will identify many more fossils with recent shells, than those who agree with Dr. Beck in dividing the same recent individuals of lucina divaricata into six or eight distinct species. Provided, however, each zoologist is consistent with himself, and provided the distinctive characters relied on as specific by each, are commensurate one with another, no confusion will arise."*

We may add that, while M. Deshayes and Dr. Beck both consider the shells of the crag as those of a northern climate, and while the latter zoologist even discovers in them a resemblance to shells of arctic seas, Agassiz pronounces its fishes, as far as they are yet known, to be all of extinct species, belonging to genera now inhabiting the tropics. The freshwater formation of Aix, in Provence, which, on the evidence of its shells, Mr. Lyell classes among the eocene strata, and the lacustrine formation of Œnengen, which some geologists considered as the most modern known tertiary deposits, have been identified by Agassiz, by means of their fossil fishes, with the molasse of Switzerland classed by Lyell with the miocene strata.

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* Proceedings of the Geological Society, vol. ii. p. 373.

It is probable that fossil ichthyology will, before long, throw much light on the chronological arrangement of the tertiary series. In fossil fishes we have the remains of animals of a higher organization than molluscs, and furnished with other solid parts than a mere testaceous covering, pervading all the strata from the oldest to the most recent, and the changes of genera and species from one system to another do not take place insensibly, like those of molluscs, but abruptly, and a tooth or a scale is often sufficient to establish, not only the order and genus, but even the species of the fish to which it belonged.

The best tests of the correctness of the principles on which the classification of Agassiz is founded, are, that it yields consistent results through the whole series of living and fossil fishes; and that when, from the examination of a mutilated specimen, possessing only scales of an unknown fish, without either head, tail, or fins, he has sketched a restoration of its form, subsequent discoveries of the entire animal have verified his predictions as to its organization. In recent as well as fossil shells, we have merely the external covering constructed by an animal without any solid parts. The animal belonging to shells of living species is often unknown to us; and we only deduce its structure from analogy. On this, to a certain extent, we may safely rely. Knowing the organization of an animal inhabiting a shell of a certain general form, we may conclude that a shell of a similar form was inhabited by an animal of a similar general structure. On this evidence, we consider that all chambered univalves, like the nautilus belonged to cephalopodous molluscs; and we infer that all shells having a canal or notch at the base, like the common whelk (buccinum undatum,) belonged to carnivorous trachelopoda, furnished with a retractile proboscis, for the purpose of boring into other shells. But when we descend to minor differences, it can scarcely be contended that those minute distinctions in the form, thickness, colour, or markings of shells, which constitute the specific differences of some conchologists, must necessarily have been accompanied by such differences in the organization of the animal, as would, without reference to the shell, have been sufficient to constitute a distinct species.

Some of the modifications of colour, size, thickness, &c., may have originated in difference of age, climate, and food, occasioning differences in the quantities of carbonate of lime secreted for the formation of the shell. With respect to age, it is certain that, in some genera, it occasions great dissimilarity in the form, for what can be more unlike than the testaceous coverings of young and adult individuals of some species of the genera cypræa and ovula?

Difficulty of distinguishing Tertiary and Recent Species. In comparing tertiary with secondary shells, the difference is so striking that a novice can scarcely mistake the one for the other, and the distinctions between those of different secondary systems is so strongly marked that there can be little danger of error; but when we compare tertiary shells (particularly those more recent than the fossils of the Paris basin) with living species, the comparison is between things so much alike that there is often considerable difficulty in detecting a difference.

We must also be upon our guard against falling into serious errors in fixing the date of these modern formations, from the proportional quantity of *unknown* shells which they contain, while our knowledge of the testacea inhabiting the seas which wash the shores of our own island is so very limited. That northern drift to which we have before alluded, as extensively distributed over Lancashire, Cheshire, and Shropshire, contains fragments of marine shells. Mr. Murchison has obtained from it many species, which have been examined by some good conchologists, including Dr. Beck, of Copenhagen, and prove to be identical with species now inhabiting adjacent seas.

In the south of Scotland there is a similar deposit, known by the local name of Till, containing, according to Mr. Smith, of Jordan Hill, broken marine shells, and occasionally, though rarely, stag's horns, and bones and tusks of the elephant. This tumultuous deposit is covered in several places, some of them eight miles from the sea, and forty feet above its level, by a tranquil deposit of finely laminated clay, containing bones of fishes and sea-fowl, fragments of sea-weeds, crabs' claws, and numerous layers of shells, the greater number of which belong to species abounding in the adjoining seas, while some of the species have become very rare, if not extinct, with reference to Scotland. On this evidence we have heard it contended that the drift of Shropshire and Scotland could not be contemporaneous, because the former contained only the remains of species inhabiting adjacent seas, while shells now extinct are found in the latter.

On the same grounds it might be contended that the deposits now forming in the Scottish seas are older than the shelly gravel lying high and dry in the centre of England, for we have been informed by Mr. Smith, that on dredging at a little distance from the mouth of the Clyde, he brought up several species of living shells that were unknown to conchologists.

The same author has since referred the till, and the raised estuary deposit of the Clyde, above mentioned, to different epochs, separated by a wide interval of time, because the former has yielded from fifteen to twenty per cent. of unknown species, whereas in the latter, which he at first supposed also to contain a small proportion of unknown or extinct species, he has recently reduced the number to one (arca papillosa), which has lately been found living on the coast of Ireland by Captain Portlock; and who can say that similar discoveries may not affect an equal revolution in the proportion of unknown species contained in the inferior till, and thus reduce the two deposits to nearly the same age?

Coralline and Red Crag, Miocene. Norwich Crag, Pliocene.

Much of the discordance of opinion which has prevailed among eminent conchologists respecting the age of the crag, has doubtless arisen from the fossils of all the different formations being blended in the collections exhibited to them under the name of crag shells. On a re-examination of the crag, in 1839, with reference to the facts announced by Mr. Charlesworth, Mr. Lyell found direct proofs of the superposition of the red to the coralline crag, and observed that the former in some places abuts against the latter, as well as overlies it. He also ascertained that the lower formation must have acquired a certain degree of consistency before the upper was deposited, because its calcareous portions are sometimes perforated by pholades, the perforations being filled with the sand of the superjacent red crag.

The Norwich crag is best exhibited at Southwold, Bramerton, Whittingham, Thorpe, and Portwick, and consists of loam, sand, and gravel, enclosing marine, land, and freshwater shells. It is covered by a dense bed of gravel, and rests on the chalk, the surface of which is in some places perforated by pholas crispatus. From the mixture of terrestrial and marine remains contained in it, Mr. Lyell considers that it must have been formed near the mouth of a river. On instituting, with the assistance of Mr. Searles Wood and Mr. G. Sowerby, a thorough examination of the shells of these different members of the crag, and comparing them with those of the faluns of Touraine, he obtained the following results:

	Number of species examined.	Identical with living species.
Coralline Crag - - -	345	about 19 per cent.
Red Crag - - - -	230	" 30 "
Faluns of Touraine - -	240	" 26 "

Of the ninety-two marine shells of the Norwich crag seventy-three species were recognised as occurring also in the red crag, but on applying the test of the proportion of recent species Mr. Lyell ascertained that the Norwich crag, both with respect to the marine and freshwater shells, contains between fifty and sixty per cent.; he therefore considers, that should these numerical conclusions hereafter require some modification, still the Norwich crag will be referrible to the older pliocene period, and the red and coralline to different parts of the miocene, thus acceding to the opinion of M. Desnoyers as to their general correspondence with the age of the faluns, though the two deposits have scarcely ten species in common, the French group exhibiting a subtropical, that of England, a northern, character. More recent still are the freshwater strata associated with the "mud cliffs," or till, which, in East Norfolk, rest on the Norwich crag.

The mammalian remains of the red and Norwich crags are in accordance with the conclusions derived from a comparison of their shells. Some teeth, procured by Mr. Lyell from the red crag of Newbourne, in Suffolk, were ascertained by Mr. Owen to be those of the leopard, bear, hog, and a large kind of deer, genera known to occur in the miocene formations of France and Germany. The more numerous mammalia of the Norwich crag are decidedly of a more recent date. Among them Mr. Lyell enumerates the teeth and jaw of mastodon longirostris, a tusk of an elephant, with serpulæ attached, and bones of a horse and hog, with those of a field mouse, larger than the common species. They are accompanied by bones of birds and fishes.

Bridlington. Sand and clay, containing tertiary shells, were discovered, several years ago, on the Yorkshire coast, near Bridlington. These Mr. Lyell has ascertained to be of the same age as the Norwich crag.

Subapennine Marls.

At the base of the Apeninnes, composed of secondary limestone, are low ranges of hills, both on the side of the Mediterranean and Adriatic, consisting of strata of marl and sand, abounding with shells, about half of which belong to existing species. These beds, once referred to the era of the Parisian tertiaries, notwithstanding the difference of their fossil contents, are found to be divisible into three groups, of which the upper and the lower occur only at particular points. These groups are:

Upper. The tufaceous deposits of Naples, the calcareous strata of Otranto, and probably the greater part of the Cambrian deposits. Newer pliocene.

Middle. Most of those of Northern Italy and Tuscany, and perhaps those of Rome. Older pliocene.

Lower. The strata of Piedmont, already described as miocene.

The most important member of the middle group consists of a light brown or blue marl, which generally forms the surface of the country, but is in some places covered with sand. It rests immediately on the Apennine limestone, gravel occasionally, though rarely, intervening. This marl is of great thickness (2000 feet at Parma), in some parts finely laminated, and abounds in shells, generally arranged in layers, indicating slow accumulation. It is occasionally interstratified with sandstone, and sometimes, though rarely, contains subordinate beds of lignite and gypsum. Lenticular crystals of the latter have been met with inclosing unaltered shells. At Radicofani, and other places, it is covered by volcanic rocks, and alternations of tufa with the marl prove that eruptions took place during its formation.

The other member of this older pliocene group consists of yellow sand and conglomerate, usually found near the junction of the secondary and tertiary rocks, generally superimposed on the marl, but in some cases resting immediately on the Apennine limestone. Near Sienna it contains alternations of fluviatile and marine shells, and may be supposed to have been a deposit poured by rivers into the sea, the bed of which was covered with the marl.

The shells are in a high state of preservation in the marl, soft when first taken up, but hardening when dried. Lapidified shells are more frequently met with in the sands, in which they have been found converted into flint and calcareous spar. The deposits contain blocks of Apennine limestone, drilled by lithodomi, remains of fishes, crabs, corals, cetacea, and occasionally terrestrial mammalia. At the base of the Maritime Alps, between Genoa and Nice, are tertiary strata, elevated from 20 to 800 feet above the sea, composed of blue marl and sand, similar to those of the Subapennines, and containing the same shells. West of Nice they are composed of thick masses of coarse shingle, in inclined beds, which are in general destitute of shells. They have been found, however, in a few seams of fine marl and sand, between the pebbly beds, of species identical with those of the Subapennines.

Strata containing the same organic remains, and of similar lithological characters, occur at the eastern termination of the Pyrenees, and in patches at Malaga, and Grenada, in Spain. They have also been discovered in the Morea.

Newer Pliocene.

Sicily. To this epoch belong the limestones, sandstones, and marls, alternating with volcanic beds in the Val di Noto, in the southern extremity of Sicily, and constituting hills from one to two thousand feet above the level of the sea. They contain shells, nearly the whole of which belong to species now inhabiting the Mediterranean; and there is decisive evidence that the alternating lavas have resulted from numerous submarine eruptions repeated at successive intervals during the formation of the subaqueous strata, which constitute with the igneous beds a mass 2000 feet thick. They may be divided into the three following groups in the descending order:

1. Great limestone formation,—a yellowish-white calcareous rock of variable character, sometimes resembling the calcaire grossier of the Paris basin. It often contains the leaves of plants and reeds, as if a stream of fresh water, holding carbonate of lime in solution, and floating down terrestrial vegetable remains, had flowed into the sea in the neighbourhood. It is sometimes more compact, resembling a precipitate from the waters of mineral springs. The thickness of the limestone is 700 or 800 feet. The thickness of the inferior groups to be next described is much less. Though the shells and corals in this limestone are nearly all of existing species, they frequently occur in the state of mere casts, as in the ancient limestones.

2. Schistose and arenaceous limestone, approaching the character of a calcareous conglomerate, sometimes tending to a pisoltic and oolitic structure.

3. Blue marls, called in Sicily *creta*, enclosing shells in a beautiful state of preservation. The order of position of these three groups is exhibited at Castrogiovanni, where the limestone of the Val di Noto is seen passing downwards into a calcareous sandstone, reposing on the marls which rest upon another series of marls containing gypsum in some parts of Sicily, and abounding in sulphur and salt.

The age of these gypseous and sulphureous marls is not yet determined; but Mr. Lyell supposes it to be of an older tertiary epoch than the newer pliocene. The base of Etna, to the height of 800 to 1000 feet, is composed of alternations of volcanic rocks, marls, and sands of the third group; the marine strata sometimes extend to the thickness of 300 feet, without any intermixture of volcanic matter. These are covered by some of the modern lavas of Etna, but there are no sections to prove that the whole cone of Etna has accumulated since the formation of the pliocene strata. In the Cyclopean Isles, a cluster of rocks to the north of Catania, where similar alternations of marine and volcanic rocks occur, the marls are much hardened and converted into siliceous schist, the lamination exhibiting contortions as irregular as those of some of the primary schists.

Extra-European Tertiaries.

America. Strata containing marine shells, a portion of which belong to existing species, have been discovered in almost every part of the world,—America, India, the Indian Archipelago, Madeira, the borders of the Red Sea, &c; but the only countries in which much progress has been made towards a knowledge of these deposits, are America and India. The geologists of the United States have divided the tertiary series of that country into three groups, according to the proportion of existing species to which they have applied the nomenclature of Mr. Lyell. The tertiary as well as the living species, differ from those of Europe. The American eocene strata rest on the equivalents of the cretaceous rocks, and their fossils approach the secondary type more nearly than those of the same age on this side of the Atlantic. Of 210 species scarcely one is known as living. The middle tertiaries contain from twenty-one to forty per cent. of recent species, and are supposed to represent the miocene and older pliocene. The area occupied by the newer pliocene is very small.

In South America, Mr. Darwin found on both sides of the Andes of Patagonia, alternations of tertiary and volcanic beds, which he considers divisible into distinct periods, on the principles adopted with respect to these deposits in Europe. The oldest contain some living species; the most recent, at a much greater elevation, consist of beds of shells identical in species with those of the neighbouring coast, particularly an extensive deposit of muscles, which retain their blue colour, and emit an animal smell when burnt.

In the Eastern Andes, a tertiary group, several thousand feet thick, and identical with these in composition and fossils, assumes a metamorphic character, as it approaches the granite, which rises in peaks 14,000 feet above the sea. It first becomes shattered, contorted and traversed by dikes and veins, proceeding from the granitic mass, and finally passes into a highly crystalline felspathic rock. In this singular overlying group are many veins of silver, copper, arsenic, and gold, which may be traced down to the granite*.

From the observations of the same author, it appears that the level and the extensive plains of the Pampas formed, at a recent tertiary epoch, an estuary into which the rivers that now unite to form the Plata discharged their waters. In these deposits he found marine shells, some of which are identical with living species, and others have a general resemblance to them, associated with many curious extinct mammalia;—the toxodon, as large as a hippopotamus, connecting the rodents with the pachyderms by manifest analogies, and with the cetacea by analogies more remote,—the megatherium, and four or five large edentata,—an immense mastodon,—the macraukenia, intermediate between the horse and the camel, but of gigantic proportions,—several rodents,—and a llama as large as a camel.

It appears, then, that the group of animals now confined to this part of the new continent were represented during the tertiary epoch, by animals of the same peculiar anatomical structure, but of colossal size; and the same remark applies to the remains discovered in Australia and India. Mr. Darwin is of opinion that in South America these huge animals continued in existence up to a very recent epoch, both because they are found in some places associated with marine shells, absolutely identical with those of the adjoining seas, and because of the slight altitude of these deposits above the sea,—elevation in those countries being so regular that its amount becomes a measure of time.

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* Proceedings of the Geological Society, vol. ii., p. 210.

India. The tertiary strata of the Sewalik Hills, on the flanks of the Himalayan Ridge, are remarkable not only for the gigantic size of some of the mammalian remains inhumed in them, but for the mixture they exhibit of extinct genera of pachyderms, characteristic of the older tertiaries of Europe, with reptiles not to be distinguished from species now living. These beds have lately yielded to Captain Cautley and Dr. Falconer, an astragalus, and a jaw-bone belonging to two species of quadrumana (one of large size), and in different beds of the same formation were found the remains of anoplotherium, with those of the magar (crocodile), and gavial, now inhabiting the Ganges. The camel, anoplotherium, and antelope, have been disinterred from the same bed. There have also been found the sivatherium, an extinct ruminant as large as a rhinoceros, and armed with four enormous branching horns, the elephant, rhinoceros, hippopotamus, hog, horse, a musk deer scarcely larger than a hare, specimens of the cat and dog tribe, the hyæna, bear, ratel, and other carnivora. Of birds, there are grallæ larger than the gigantic crane of Bengal; of reptiles, besides the magar and gavial, there are other crocodiles of enormous size; of testudinata, ordinary sized species of emys and trionyx, with humeri and femora of other species, as large as the humerus and femur of the Indian rhinoceros, and corresponding fragments of bucklers.*

No human remains have yet been found in any tertiary strata; and from the absence of bones of the monkey tribe, in deposits which in Europe have yielded so many mammalian remains of a tropical aspect it was supposed that those animals which approached the nearest to the human form dated their origin from the birth of man. Bones of monkeys, however, have now been discovered at Sausan in France, in calcaire grossier, in the Sewalik Hills, in company with anoplotheria, and beneath the city of Calcutta, and more recently in the London clay near Woodbridge. The resemblance between some of the extinct animals of two such distant regions as France and India, is not confined to mammalia. Shells, identical in species with those of the Paris basin and London clay, have been found on the banks of the Irawadi, in the northeast of Bengal, and in the district of Assam, 1500 feet above the sea. On the Irawadi, the strata of marl and limestone containing them were covered by deposits of sand and gravel, in which were found remains of two species of mastodon, hippopotamus, rhinoceros, hog, ox, deer, and antelope, a crocodile, and gavial, identical with or closely resembling living species, and several species of emys and trionyx, one of which was of very large size.

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* Proceedings of the Geological Society, vol. ii., p. 560.

CHAPTER XIX.

OSSIFEROUS CAVERNS.—ERRATIC BLOCKS AND DILUVIUM.—RAISED BEACHES.

Distribution of mammalian remains in tertiary and superficial accumulations.—Ossiferous caverns of Germany; England; Kirkdale Cave—osseous breccias of the Mediterranean—cave of San Ciro.—Raised beaches—afford proofs of recent elevation of the land in many parts of the world—the Scandinavian peninsula now rising—raised beaches of the British Isles—distinct from conchiferous diluvium.—Erratic blocks and diluvium—dispersion of erratics from Cumberland, to the east and south—accompanied by marine shells—diluvial deposits of North Wales—absence of proofs of slow accumulation—evidence of violent and transient action on pre-existing land—mammalian remains beneath northern drift in Cefn Cave—gravel works of Talargoch mine—conchiferous diluvium of Ireland—diluvial deposits of the southeast of England—investigation of diluvial phenomena too much neglected.—Recent discovery of a forest beneath diluvium, by Mr. Lyell.

Distribution of Mammalian Remains in Tertiary and Superficial Accumulations.

The mammalian remains of the miocence and pliocene epochs are found under the following variety of conditions:

1. Drifted into seas and estuaries, accompanied by marine shells, and sometimes covered with balani and flustræ, showing that they had remained for a considerable time as bare bones at the bottom of the sea; contemporary with these, were accumulations on the surface of the land.

2. In lacustrine and fluviatile deposits mixed with land and freshwater shells, as at North Cliff, near Market Weighton, in Yorkshire, at Brentford, Stratford, and other places in the valley of the Thames, besides numerous localities in other parts of England and on the Continent.

3. In caverns, such as the Kirkdale Cave in Yorkshire, which appears to have long been the abode of hyænas, by whom the remains of various animals were dragged in for food. Into others, as the bear caverns of Franconia, the animals may merely have retired to die.

4. Grazing quadrupeds have fallen into open fissures, and their bones accumulating during a long period, and mixed with debris

of the rock, have been cemented by the infiltration of the carbonate of lime into osseous breccias, such as that of Nice, Gibraltar, and the Mendip Hills. These open fissures are, in many cases, connected with caves, and have been the means by which bones were introduced into them, currents of water carrying them forward, and lodging them with pebbles and silt wherever there was a hollow in the floor.

5. Remains of terrestial mammalia are found in accumulations of alluvial gravel, covered by lava. Bones of quadrupeds belonging to the miocene period, are so entombed under some of the lavas of the extinct volcanos of Central France, which commenced their action in the eocene epoch.

6. Another condition under which mammalian remains occur is mixed with marine shells, all of existing species, and with large boulders and smaller detritus transported from a great distance, by extraordinary marine currents which traversed land as well as sea. Strange as it may appear, this deposit, though one of the most recent, is that about which geologists know the least. It has been its constant fate to be the sport of hasty generalization. First, it was treated as the effect of atmospheric erosion on dry land, its transport was attributed to river agency, or the bursting of lakes, and it was appealed to as a proof of the high antiquity of our present continents. When it was found that in the British Islands, in Northern Europe, and Northeastern America, the superficial deposits afforded evidence of the violent action of extraordinary currents from the north, all the transported matter of these different regions, and not of these only, but of the whole world, was assumed, on insufficient evidence, to have been contemporaneous, and was ascribed to the Noachian deluge; and because the marine and lacustrine strata of the miocene and pliocene era contained the same mammalian remains, they were all confounded with it under the name of diluvium.

In the course of a few years, it was discovered that the lacustrine and marine strata afforded unequivocal proofs of slow accumulation, that they represented at least two zoological epochs, graduating into each other, and into that of the older tertiaries of the Paris basin, and that the introduction of the species constituting the existing creation was gradual. Proofs were also collected of local elevations of the land, and of the littoral deposits surrounding it, either by a process of long-continued and imperceptible intumescence, or by successive movements of a few feet at a time, from the shocks of earthquakes; in some instances since the neighbouring land had been inhabited by man (the coasts of Naples and Sweden), in other cases (the Morea, Isle of Jura, Devonshire), at an epoch, the date of which could not be determined with greater precision than that the elevation took place after the neighbouring seas were inhabited by the groups of testaceous species at present existing in them.

About the same time it was found that the detrital deposits drifted from the north, contained in various parts of the British Isles (Wales, Cheshire, Lancashire, Shropshire, and Ireland) broken marine shells of existing species, and they were immediately seized upon by some influential geologists as raised beaches or littoral deposits accumulated during a long-protracted epoch, and raised to their present situations by movements of elevation of unequal intensity.

A careful examination, however, of the phenomena of this transported detritus shows that this opinion is quite untenable; for, in the first place, the deposit manifests none of those indications of gradual formation which are found in undoubted sea-born strata; and, secondly, it affords proofs of violent and transient action and rapid accumulation; and, lastly, it can be shown that at least one ossiferous cavern, within the area of the northern drift of England, into which it has entered, was inhabited by terrestrial mammalia before this shelly gravel was spread over the surface.

At the same time it must be admitted that, while the greater part of this tumultuous deposit spread over the British Isles was supraterrestrial, other portions of it were submarine, and have been brought to light by the local elevation of parts of the coast of our island, so that they are seen covered by a raised littoral deposit at Speeton, on the coast of Yorkshire (Phillips), or by an estuary deposit on the banks of the Clyde (J. Smith); but there is, as yet, no well established instance in the British Islands of one of these elevated marine deposits at a greater height than 100 feet, and their elevation above the sea is generally much less.

It appears, then, that ossiferous caverns and raised beaches must be studied in connexion with erratic blocks and diluvium. Taking them, according to our views, in chronological order, they would stand thus: ossiferous caverns, diluvium, raised beaches. We shall, however, deviate somewhat from this order in treating of them: first pointing out the phenomena of bone caverns, indicative of their having long been inhabited by terrestrial animals; we shall then discuss the evidence afforded by raised beaches and littoral deposits of long submergence and gradual accumulation; and, lastly, we shall describe the diluvial deposits of the British Islands, to which, in the present state of our knowledge, it is best to limit our generalizations, because their epoch is determined by the presence of marine as well as terrestrial remains, and we shall point out the circumstances in which they differ from raised beaches and regular marine strata.

Ossiferous Caverns.

Ossiferous caverns are generally situated in limestone, not that the bones have any necessary connexion with that rock, but that caverns are more abundant in calcareous rocks of all epochs, particularly when they constitute thick beds, than in those of a different nature. Their communication with the surface by means of fissures and swallow-holes may frequently be traced, and it is by no means uncommon to find them the channels of subterranean rivers; and even when these are absent, they are generally wet from the percolation through the stone of water holding calcareous matter in solution, which it deposits as crusts of stalagmite on the floor and sides, or as stalactite, pendent like icicles from the roof.

We may therefore ascribe the origin of these caverns to fissures, produced during some movement of elevation, and enlarged by the solvent power of acidulated water.

Osseous caverns and fissures abound in every part of the world. They are too numerous even to give a mere list of them. There are many instances of them in England, in the south and east of France, in the Ardennes, the Hartz, Franconi, Wirtemburg, Switzerland, America, India, and Australia. They abound with the remains of elephants, large animals of the feline family, rhinoceros, stag, hyæna, ox, deer, and other smaller animals.

On comparing the osseous contents of the different caverns of a given district, as England, we find them possessing a certain general analogy, and distinguished by characteristic differences from those of another district as Germany. This local peculiarity is an important fact, as proving, in addition to other evidence furnished by the state of the remains, that the animals were inhabitants of the districts where their bones are found, and it is also an argument in favour of the existence in those situations of extensive tracts of continuous land, constituting distinct zoological provinces.

The caverns of Germany, (Gailenruth, Scharzfield, Rabenstein, with many others, too numerous to mention,) are described by Cuvier as exhibiting nearly an identity of species for an extent of 200 leagues, by far the greatest portion of the remains contained in them being referrible to two extinct species of bear, (ursus spelæus, and ursus arctoideus,) the remainder consisting of an extinct hyæna, (the same species as that of many of the English caverns,) a felis, glutton, wolf, fox, and polecat. The extinct pachyderms of the eocene period have never been found in any cavern. The bones brought from Australia are referred by Mr. Clifft to the kangaroo, wombat, dasyrus, kaola, and phalangista, most of them of species now inhabiting that country. Three or four were unknown to zoologists, and one, larger than the rest, was supposed by Mr. Clifft to belong to the hippopotamus.

Caves of Germany.

In the German caverns, the bones are generally enveloped in sediment consisting of a brown argillaceous earth or mud, containing a considerable proportion of animal matter, covered by stalagmite, and having stalagmite diffused through it. They are sometimes scattered singly through all parts of the mud, from the entrance to the inmost recesses of the cave, sometimes accumulated in masses twenty feet in depth. These accumulations generally occur in hollows in the floor. The animal remains are not met with as entire skeletons, but as detached bones from different parts of animals of all ages. The skulls and heavier bones are generally in the lower part of the mass, the longer and lighter bones in the upper part. The floor on which they rest is sometimes worn and polished, by the walking or rubbing of the animals. Rounded pebbles sometimes accompany the bones, which, in that case, are much crushed, but not when the sediment is destitute of pebbles. The inferences from these facts are, that the caverns had remained open for a long period, and had been inhabited by carnivorous animals, or had been retreats, into which bears, according to their well-known habits, had retired for shelter or to die in quiet; and that the pebbles were drifted in by a current of water from the neighbouring country. Of the nature of that current, there are now differences of opinion. It was once considered coeval with the dispersion of the Scandinavian boulders, which are spread over the sandy plains of Northern Europe, from the Baltic to the banks of the Niemen, the Dwina, and the Neva, was assumed to be contemporaneous with erratic gravel and boulders in all other parts of the world, and ascribed to the Noachian deluge.

Many geologists now attribute the collection of the mud and pebbles within the caves to inundations of the neighbouring rivers, or to the action of subterranean currents which received them from fissures into which the carcasses fell.

The position of the entrance of these ossiferous caverns in cliffs overhanging rivers or the sea, at a considerable elevation above the existing streams and coasts, and in situations extremely difficult of access—a fact of very common occurrence even in cases where the caves must have been inhabited dens—renders it probable that there has been a change of level, either by erosion or elevation, or by both, since the period when they were frequented by the animals whose remains are found in them. Kirkdale, Rabenstein, and Bauman's Hohl, afford examples of this. At Bauman's Hohl, the river Bode, flowing formerly at a higher level, may have thrown the pebbles and silt into the cave's mouth; that of Zahnloch does not admit of river agency for their introduction, as it is situated on a hill 600 feet above the valley of Muggendorf, and the bones occur in loam mixed with angular pieces of limestone. In those cases, by far the most common, where there is but one deposit of mud covered by one layer of stalagmite, it must be admitted that the inundation, whatever its nature, which introduced the pebbles was succeeded by a long interval of repose, during which the calcareous crust was formed; but cases occur, as at Chockier, near Liege, in which several deposits of ossiferous sediment are separated by stalagmite. In these caves there must have been several successive inundations.

English Caves. Kirkdale.

Kirkdale Cave in Yorkshire, and Kent's Hole near Torquay, are instances of dens which have been inhabited by hyænas. We shall confine ourselves to a description of that of Kirkdale as the most characteristic. It is situated in a very thick part of the coralline oolite, on the northern side of the Vale of Pickering, about thirty feet (according to a recent measurement by Professor Phillips) above the stream of the Hodge Beck. The entrance is supposed to have been blocked up with stones and rubbish, and the cave was discovered by an opening made into it laterally in working a quarry. The length explored is about 250 feet. Soon after its discovery it was carefully examined by Dr. Buckland, who has described the floor as nearly level, and conformable to the stratification of the limestone. The roof, likewise is, formed by a nearly level bed of rock, and is in general so low that a man cannot stand upright in the cave, except in two or three places where there are open fissures. The bottom is covered with a yellow sediment, the surface of which, when the cave was first explored, was nearly smooth and level, except where its regularity was broken by the accumulation of stalagmite, or ruffled by the dripping of water. It consists of an argillaceous and slightly micaceous loam, composed of such minute particles as would easily be suspended in muddy water, and is mixed with much calcareous matter derived in part from the dropping of the roof, and in part from comminuted bones. Towards the interior it becomes more coarse and sandy. Be-

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neath this sediment, the solid rock was partially covered with stalagmite, which had been formed before the introduction of the mud. Bones were dispersed through this mud at all depths, and were found in the midst of the upper stalagmite, and sticking up through it. See the annexed diagram (195,) from *Reliquiæ Diluvianæ.*

The bones were those of the following animals:—*Carnivora:* hyæna, tiger, bear, wolf, fox, weasel. *Pachydermata:* elephant, rhinoceros, hippopotamus, horse. *Ruminantia:* ox, and three species of deer. *Rodentia:* hare, rabbit, water-rat, and mouse. *Birds:* raven, pigeon, lark, a small species of duck, and a bird about the size of a thrush.

The most numerous remains were the bones and teeth of the hyæna. They were found in the jaws in every stage of growth, from the milk teeth to old grinders worn down to the stump. The remains of the ox and water-rat were very abundant; the teeth of the elephants were chiefly those of young animals; those of the rhinoceros and hippopotamus were rare. The bones of all these animals were mixed indiscriminately together, and strewed over the floor "as in a dog-kennel," and some of the largest bones were found in the narrowest recesses of the cave. It is the well-known habit of the Cape hyæna, after picking the flesh from the bones of its prey, to crack them with its strong teeth, to suck out the marrow, to devour the small chips of bone, and to gnaw and lick the more solid parts which cannot be reduced to fragments small enough to be swallowed. Almost all the bones at Kirkdale appeared to have been subject to this treatment. They were broken by simple fracture, and exhibited abundant marks of hyænas' teeth. Some of them were polished on one side, as if from the trampling of the animals, or from their rolling on the floor strewed with bones. A further proof of the cave having been the abode of hyænas, was furnished by the fecal balls of album græcum containing fragments of bone, which were found in it in considerable quantities.

The conclusions which Dr. Buckland drew from these facts, and from which it seems impossible to dissent, were that the Kirkdale cavern had long been occupied as a den of hyænas, who dragged in the entire or mangled carcasses of other animals inhabiting the neighbourhood; that the mud had been introduced by a flood, after which it ceased to be inhabited by these animals, and the sediment became covered by a crust of stalagmite, marking the lapse of a considerable period of time. These views were confirmed by comparing the mangled state of the bones in this cave and in Kent's Hole, where remains of hyænas were abundant, with their more perfect condition in other caves containing few or no hyænas' teeth.

Barwell Cave, in the Mendip Hills, is an open fissure, containing bones of ursus, felis, cervus, and bos, mixed with fragments of the limestone rock. The infiltration of calcareous matter would cement the mass into an osseous breccia, like those of Gibraltar, Nice, &c.

Osseous Breccias of the Mediterranean.

Many of the caves and fissures on the shores of the Mediterranean appear to have been marine, and afford evidence of elevation. That of Nice is described by Mr. De la Beche as a fissure formed in dolomitic limestone. The sides of it are bored by lithodomous molluscs, and as the perforations contain shells of different ages, it must have been long submerged. The bottom of it is chiefly filled with rounded pebbles, composed of fragments of rocks transported from a distance, and cemented by a compact calcareous base; the upper part is filled with broken bones of land animals, marine and freshwater shells and detritus, chiefly, but not entirely, derived from the neighbourhood, and united by a reddish calcareous cement.

Cave of San Ciro. The caves and osseous breccias of San Ciro and Beliemi, near Palermo, described by Hoffinan and Dr. Christie, afford some curious phenomena. That of San Ciro is distant about two miles from Palermo, is twenty feet high, and ten feet wide, and is situated in secondary limestone in the Monte Grifone, at the base of a rocky precipice, about 180 feet above the sea. From the foot of the precipice an inclined plane of conglomerate, containing shells of species now inhabiting the Mediterranean, extends to the sea, distant about a mile. It contains fragments of the yellow newer pliocene limestone, (see page 388,) and is therefore younger than it. Its sea-shells attest its marine origin, and perforations on its calcareous pebbles prove it to have been long beneath the sea. Of the same age with this is the bone breccia. This is not confined to the cave, but forms a great part of the external talus, where it rests immediately upon the conglomerate or raised beach, and is about twenty feet thick. The breccia is composed of numerous fragments of bones, with some rolled pieces and blocks of limestone, cemented together by a little lime or clay; and it has some appearance of stratification, indicating a deposit from water. The bones were pronounced by Cuvier to be those of the elephant, hippopotamus, and deer, with a few of a carnivorous animal of the genus canis. Immediately above the level of the raised beach, serpulæ are found adhering to the rock, and the limestone is perforated by lithodomi. Within the grotto also, at the same level, and *beneath* the osseous breccia, similar perforations are so numerous, that the rock was compared by Hoffman to a target pierced by musket-balls. Many of the bones are rolled, as if partially subjected to the action of the waves. Beneath the breccia is a bed of sand, filled with marine shells, resting on the limestone of the cave.

Above the level of the marine sand the rock is jagged and uneven, as is usual on the sides and roofs of limestone caverns; below the sand it is smoothed and polished, as if by the attrition of the waves. Many ship-loads of bones have been removed from the cave. In a cave near Syracuse, above the level of the sea, formed in tertiary rocks, there is a breccia of the same age as that of San Ciro, containing similar bones and marine shells, which has not only been worn by water since its deposition, but its substance has been perforated by lithodomi. From these circumstances it is inferred by Dr. Christie that the extinct mammalia whose bones are found in the breccia, must have lived at a period long posterior to that in which the Mediterranean began to be inhabited by its present species of molluscs, radiata, and zoophytes, and before the last movement by which a great part of Sicily was raised above the sea. At Beliemi, four miles west of Palermo, Dr. Christie visited two other caves: in the one, bones are only found in a talus at its mouth; in the other, they occur both in the cave and in a talus which slopes from its mouth to the level of the plain below. These caves are at a greater height than the other tertiary rocks have attained in that neighbourhood, and neither the caves themselves, nor the bone breccias, have any appearance of marine action; from which he inferred that the breccias of Beliemi were above the surface of the sea at the time that of San Ciro was beneath it, and that the present heights mark the extent of the last movement of elevation to which Sicily has been subject.*

It may be as well also to mention that he notices a diluvial deposit, of which he distinguishes two kinds, differing in age. The oldest is of the same era as the conglomerate and bone breccia, occurs at considerable heights on the sides and summits of the hills, and is composed of large rolled fragments of sandstone, with a few fragments of tertiary rocks, cemented by a sandy clay. The newer diluvium occupies the bottom of the valleys sometimes to great depths, and with fragments of older rocks, enveloped in a great quantity of gray clay, contains pieces of the conglomerate itself.

We have detailed the phenomena of the cave of San Ciro thus minutely, because when the case of Cefn Cave, in Denbighshire, which contains marine and terrestrial remains, was brought under the notice of the Newcastle meeting of the British Association, Mr. Lyell treated the two cases as parallel, whereas it appears impossible for two cases to be more dissimilar, the marine remains being in the one case beneath, in the other above, the bones; as will be seen when we come to the description of Cefn Cave, which it will be best to postpone till we treat of erratic blocks and diluvium, with which its phenomena are so intimately connected. We shall, therefore, proceed to the consideration of raised beaches and littoral deposits, of which the cave of San Ciro affords one instance.

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* Proceedings of the Geological Society, vol. i. p. 336; and Principles of Geology, vol. iv. p. 55.

RAISED BEACHES.

If we examine any of our existing shores we shall find that they may be divided into three portions:

1. That comprised between the high water of spring and neap tides.
2. That comprised between the high water of neap tides and the extreme low water of spring tides.
3. An expanse of sand and gravel, of greater or less extent in proportion to the flatness or steepness of the shore, never laid dry, but covered, even at the lowest ebb, by shallow water.

These may be called high-water beaches, low-water beaches, and littoral sea-bottoms.

A high-water beach is distinguished by the following characters: A terrace of shingle is thrown up, more or less steep, composed of smooth round pebbles, mixed with which are a few whole and many broken shells. The rocks that bound the coast, and points of rock projecting through the beach, as well as large boulders lying on it, are polished and worn into hollows by the action of the breakers. The rounded calcareous pebbles contained in it exhibit nearly obliterated traces of lithodomous perforations.

A low-water beach usually presents a gently sloping surface, often thickly strewed with pebbles and blocks, with intervening patches of sand. The pebbles, being not so much disturbed as near the line of high water, are less water-worn; calcareous pebbles and rocks are perforated by lithodomi, and non-calcareous pebbles are incrusted with balani and serpulæ; the lower parts of rocks and large boulders are partially water-worn, but the upper surface, and any of the lower parts that are protected from the grinding action of the waves charged with sand and pebbles, are covered with balani, &c., often so thickly that the entire surface is concealed by them. Small patches of sand between the boulders and pebbles are inhabited by several species of testacea, and in crevices of the rocks, or between the boulders and pebbles, are wedged whole or partially broken shells, the valves of conchifers being generally but not invariably separated.

The incrustations are more numerous, and the whole shells more abundant, on that part of the shore constantly covered by shallow water; and on flat coasts, and in the wider part of straits, like the Menai, there are banks of sand left dry at half tide, and inhabited by conchifers, such as cardium edule, solen vagina, tellina solidula, whose dead shells are buried in the sand in great quantities, with the two valves united. Beds of mytilus edulis are found adhering to banks and rocks, partially uncovered at low water.

To these may be added a fourth case of bold cliffs, the base of which is never left dry by the recess of the tide, and on such cliffs the line of high water is marked by caverns and hollows worn in the rock by the action of the breakers. The base of the rock, which is wholly covered, or seldom long uncovered, is incrusted with balani and serpulæ, and when calcareous bored by lithodomi.

Proof of Recent Elevation in many parts of the World. Innumerable examples of elevation of land, and in some instances of successive elevations, attested by one or other of the above effects of littoral action, and occuring at various heights above the level of the sea, have lately been collected by the industry of observers in all quarters of the world. In the coral islands of the Pacific, in Sicily, Iceland, and the coast of Chili, these alterations of level are found within the range of active volcanos. In Great Britain and Ireland, and on the coast of Sweden, they have taken place in countries where volcanic action is extinct or quiescent, and where violent shocks of earthquakes are seldom felt.

In the following countries elevations have taken place since they were inhabited by man. Oscillations of the coast near Naples are proved by molluscous borings on certain parts of the columns of the Temple of Serapis, near Puzzuoli; and it can be ascertained that this depression and re-elevation took place between the third century, when inscriptions on the temple prove it to have been in its original position, and the beginning of the sixteenth century, when it is on record that its site was still submerged.*

In the Island of San Lorenzo, near Lima, works of art of Peruvian manufacture were found among beds of shells of the species inhabiting the adjacent seas, evidently imbedded at the same time with the shells, and elevated eighty-five feet above the sea.†

Scandinavian Peninsula still Rising.

Sweden affords an instance of the gradual and imperceptible rise of land continued to the present time. The fact had long been suspected, on the evidence of rocks elevated above the water, which were known to have been sunken reefs,—seaports, in the Gulf of Bothnia, become inland cities,—small islands joined to the continent,—and old fishing grounds deserted from the shallowness of the water. Celsius, who drew attention to these phenomena about a century ago, attributed them to a gradual subsidence of the Northern Ocean, which he estimated at about forty inches in a century. This opinion was controverted by many contemporary philosophers, because of the impossibility of such subsidence in the seas of any one region without a general sinking of the waters of the whole earth, of which other countries afforded no evidence. They even denied the fact of a change of level in the Baltic, appealing to the position of certain towns on its southern shores, as Lubeck, Stralsund, &c., which were as little elevated above the sea as at the era of their foundation, and they ascribed to the accumulation of sediment discharged by rivers into an inland sea the increase of shoals, and the other phenomena of the Gulf of Bothnia, pointed out by Celsius. Playfair admitted the change of level, but denied the subsidence of the sea, and contended that it was due to a gradual rise of the land. Von Buch, after having examined the country, in 1807, declared that the whole of Scandinavia, from Frederickshall in Sweden, to Abo in Finland, and perhaps to St. Petersburgh, was insensibly rising; and he founded his opinion, not only on information derived from the inhabitants, but from having met with marine shells of existing species at several points on the coast, considerably elevated above the sea. In order to ascertain the truth on a point which had given rise to so much controversy, the Royal Academy of Stockholm had caused marks to be cut on the rocks in various places along the coast, indicating the ordinary level of the water in a calm day; and as the Baltic is nearly a tideless sea, it affords great facilities to such observations. On an examination of these marks, in 1820, they were found to indicate a change of level, but the amount had not been equal in equal periods of time, and new marks were fixed as a guide for future observers.

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* Consult Principles of Geology, vol. ii., p. 324.

† Mr. C. Darwin, as cited by Mr. Lyell, Elements of Geology, p. 296.

On examining these fourteen years afterwards, Mr. Lyell was satisfied that in the interval the change of the level had amounted, in certain places north of Stockholm, to as much as four or five inches; and that it diminished from north to south, being less near Stockholm than in the upper part of the Gulf of Bothnia, while in Scania the southern province of Sweden, it was imperceptible.

That this change of level was caused by the rise of the land, not by the partial draining or filling up of an inland sea, is proved by the western or Atlantic coast, between Uddevalla and Gothenberg, exhibiting the same indications of a change of level as the shores of the Gulf of Bothnia; that it has been in progress for a long period, is indicated by the fact that marine remains, all identical with existing species, are found at various heights, amounting to 200 feet, and in the northern part of Norway to as much as 400 feet. This fact, first annouced by Von Buch, has been confirmed by Brongniart and Lyell, the two last observers having found balani adhering to the rocks to prove their long submergence. The greatest distances from the sea at which marine remains have been found, are about fifty miles on the side of the Atlantic, and seventy miles on that of the Gulf of Bothnia. Marine shells of existing species have also been collected at inland places near Drontheim, in Norway, but there is reason to believe that the elevatory process is now stationary there. In the province of Scania there are indications of depression and re-elevation, like that of the Temple of Serapis, at Puzzuoli; for in making an excavation an ancient hut, on the floor of which was a rude fire-place with cinders and charred wood, was found beneath sixty-four feet of marine strata. The observations of MM. Pingel and Graach seem to prove that Greenland is undergoing a movement of an opposite kind to that which is taking place in Sweden, for the habitations of the Esquimaux, and of the early Danish colonists are now submerged at high water.

Raised Beaches of the British Isles.

Although we have no proofs that the British Islands have been elevated since they were inhabited by man, we have around our shores many raised beaches, attesting elevation since the existing species of molluscs were established in the adjoining seas. These have been found on the coast of Banffshire, at from six to twelve feet above the reach of the highest tide (Prestwich); in the Valley of the Forth (Boué and Maclaren); at Speeton, covering the lower parts of the diluvial cliffs (Phillips); at Brighton, beneath the elephant or diluvial bed, about twelve feet above the sea (Mantell); at Plymouth, and other parts of the southern coast of Devonshire, at various heights not exceeding seventy feet (Hennah and Austen); in Barnstable Bay, seventy feet (Sedgwick and Murchison); in Cheshire at the base of the Forest Hills, beneath diluvium at the height of seventy or eighty feet (Sir P. Egerton). *Perhaps*, at about the same height, at the mouth of the Clywd in Denbighshire, and at Preston in Lancashire, likewise beneath diluvial accumulations; but the evidence is not satisfactory, and if raised beaches exist at these points, their elevation does not exceed a hundred feet, the marine shells which accompany the northern erratics at greater heights not being, *per se*, any proof of elevation.

On the banks of the Clyde, at Glasgow, Paisley, Greenock, also near Loch Lomond, an estuary deposit, containing marine and terrestrial remains, and bearing abundant marks of gradual accumulation, covers diluvial or boulder clay, at various heights, from thirty to seventy feet above the sea (J. Smith). In the Isle of Jura, six or seven terraces of smooth round pebbles, like those of the adjoining beach, are found at various successive heights, up to forty feet above the sea, accompanied by lines of caves in the cliffs, apparently sea-worn (Captain Vetch).

In Ireland the only deposits of recent shells at present known, containing unequivocal proofs of slow accumulation, are found in the county of Derry on the banks of the Foyle, in the neighbourhood of Dundalk, and at the head of Carlingford Bay. In the two first named places the height does not exceed twenty feet above the sea, and it is probably not more at Carlingford, though the amount of elevation has not been ascertained, or at least is not stated.*

The conchiferous gravel accompanying northern boulders in Caernarvonshire and other parts of North Wales, and in Lancashire, Cheshire, and Shropshire,—also in Ireland, on the coasts of the counties of Dublin and Wicklow,—is classed by some of our most eminent geologists, (Murchison, Lyell, and Phillips,) with raised beaches; but we have ventured to exclude it from the list, being convinced by a long and careful examination of it, that it affords no proofs of long submergence, and of the action of ordinary marine currents, but many of rapid accumulation on the surface of the land. The deposits of the county of Wexford require further investigation before it can be decided whether any, and what portion of them afford proofs of elevation.

Erratic Blocks—Diluvium.

(*Northern Drift; Till; Boulder Formation; Terrain de Transport; Mud Cliffs.*)

Under this head we include deposits of clay, sand, and gravel, containing either marine shells of existing species, or mammalian remains of extinct species, or both, affording no proofs of long submergence, many of rapid accumulation. Amidst much local detritus, these deposits contain fragments which may be traced to their parent rocks, often more than a hundred miles distant. These fragments are frequently many tons in weight and then acquire the name of erratic blocks. The mode of their distribution indicates the direction of the currents by which they were transported, showing them to have been of extraordinary energy, capable of surmounting great inequalities; yet respecting, in some degree, the present general configuration of the surface. Checked in their course by mountain barriers, they have in places surmounted them, and have descended from the points where they effected a passage along the present valleys, but without reference to the levels of existing drainage, the lines of which they generally follow, but often cross. The mass of the detritus is less waterworn than that of a river or a beach, and is generally heaped confusedly together, without any indications of regular stratification, and without reference to the size, magnitude, or specific gravity of the component materials; fragments derived from various quarters, large and small, rounded and angular, being imbedded in clay or fine sediment, in which huge boulders are enveloped, sometimes in positions into which they would not have settled by the force of gravity. These deposits are, however, occasionally stratified, or even finely laminated; but the stratification is persistent over small spaces only; the same bed is rarely continuous for 300 yards; the most finely laminated portions pass on the same plane into the unstratified, and have never yet furnished an instance of a

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* Journal of Geological Society of Dublin, vol. i. part 3, p. 180 and 256.

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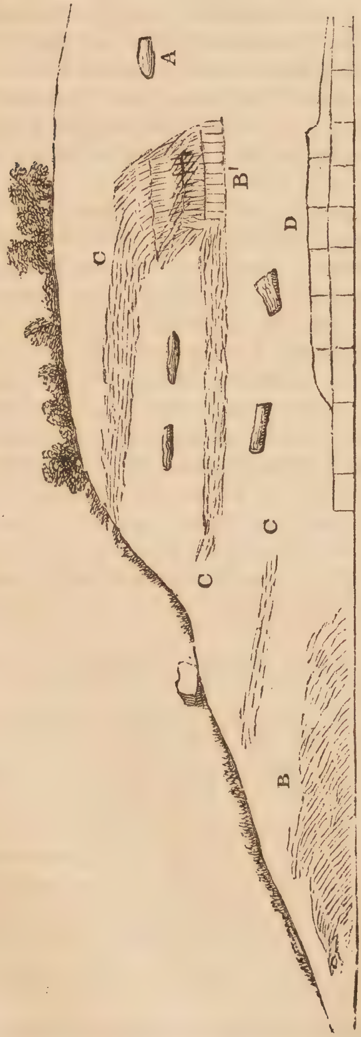

SECTION AT THE TY'N Y FRIDD QUARRY, NEAR BANGOR, 1829–30.

A. Brown loam, with boulders.
B B'. Angular fragments, and broken tops of purple slate.
C C. Insulated masses of these, enveloped in the boulder deposit, and retaining their vertical positions at B'.
D. A flat surface, grooved and scratched.

layer of shells, in different stages of growth, following laminæ of stratification, nor of a bivalve shell with the two valves united. They are destitute with two exceptions, which will be noticed hereafter, and which admit of easy explanation, of lithodomous perforations on their calcareous pebbles, and of marine incrustations on those which are not calcareous, neither have incrustations or perforations been found on the rocks beneath them; but their surface is marked by scratches, grooves, and indentations, named by Sir James Hall "dressings." Or the surface of the rocks exhibits indications of an ancient weathering, older than the transported matter. These indications consist of a rubbly mass of angular fragments, and are most strikingly exhibited in the soft slate rocks, traversed by numerous horizontal joints. The upper part of such rocks is bent and broken beneath the incumbent diluvium; some of the angular fragments are dispersed through it, but they frequently form a layer between the rock and the transported matter, or have been lifted up bodily and enveloped in it. (See diagram 196.)

The general direction of the diluvial currents, by which this heterogeneous mass was distributed over the British Isles, has been from northwest to southeast, modified however by the local configuration of the surface. Commencing at the Ultima Thule, we find strong traces of a diluvial current, noticed by Mr. Murchison and Professor Sedgwick, having a direction N.N.W. and S.S.E. on the hills of the Brora district of Sutherland.* The "Till" of the southwest of Scotland, already mentioned (p. 385,) contains boulders of rocks which can be traced to a more northern region, and some blocks of Scottish rocks have crossed the Solway Frith. The local nature of the gravel below the openings of the valleys which descend from the Grampians, appears quite compatible with the action of a great current traversing that range, as will be shown hereafter when adverting to the same phenomena in parts of the Cambrian mountains.

Dispersion of Cumbrian Erratics to the East and South.

The dispersion of the granitic, syenitic, and porphyritic detritus of the mountains of Cumberland, southwards as far as Worcestershire, and eastwards to the mouth of the Humber, is highly instructive; the phenomena have been studied by numerous observers, the scattered masses are easily identified with their parent rocks, and the district from which they have been derived is small and well defined. Boulders from these mountains have been driven eastward across the limestone ridge of Orton and the vale of Eden,—a pre-existing valley, filled with new red sandstone. They have crossed the Penine chain, but only at one point, and that the lowest pass opening directly to the west, about 1400 feet above the sea, nearly level with the present summits of the mountains whence they were derived, and 900 feet above the vale of Eden. The summit of the pass of Stainmoor attained, they have rolled down the eastern slope of the Penine chain, have traversed the vale of Tees to Redcar, and the vale of York to the Humber. The oolitic and chalk ranges of the moorlands and the wolds, have opposed obstacles to their passage eastward similar to that presented by the Penine chain, though on a smaller scale, and these obstacles have been surmounted on a similar manner at their lowest points ; so that blocks of granite from Shap Fells are found near Scarborough and Flamborough Head. Detritus from the Cumberland mountains has likewise been borne eastward to the mouth of the Tyne, along the depression caused by the Tynedale fault at the northern termination of the Penine chain, though the streams flowing in that direction are quite unconnected with the mountains from which the detritus was derived.

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* Proceedings of the Geological Society, vol. i. p. 34.

Parallel to the course of the Penine chain, a small portion of the Cumbrian erratic blocks have gone northwards along the vale of Eden to Carlisle, and an immense quantity of them has been drifted southwards, by Lancaster, and the narrow tract between the mountains and the sea, crossing the drainage of the Lune, Ribble, Wyre, Weaver, Mersey, and Dee, and spreading into the valleys of the Severn and the Trent. Blocks of large size are found as far to the south as Bridgnorth, from which point they decrease in size and quantity, and pass off into coarse gravel composed of the same materials, which gradually dies off into the fine gravel and silt of the vale of Gloucester.

Marine Shells in Diluvium.

Marine shells of existing species accompany the erratic blocks in their course from the banks of the Ribble to Bridgnorth. The large blocks are not confined to the surface, as was once supposed, but are dispersed through the gravel, sand, and clay. Neither are they confined to the valleys, but are found at various heights on the northern flanks of the Wrekin and Haughmond Hills, and the northern skirts of the old red sandstone district of Herefordshire, into which, according to Mr. Murchison they have not penetrated, the detritus of that region being wholly local. This circumstance he endeavours to explain by supposing that Wales and Siluria were separated, up to a very recent epoch, from England by a strait of the sea, the eastern shore of which was bounded by the Cotswold Hills, and that granitic and other northern boulders were transported on ice and deposited at the bottom of this sea. An objection to this hypothesis is their rounded and waterworn condition, and their diminution in size and quantity from north to south. Another formidable ob-

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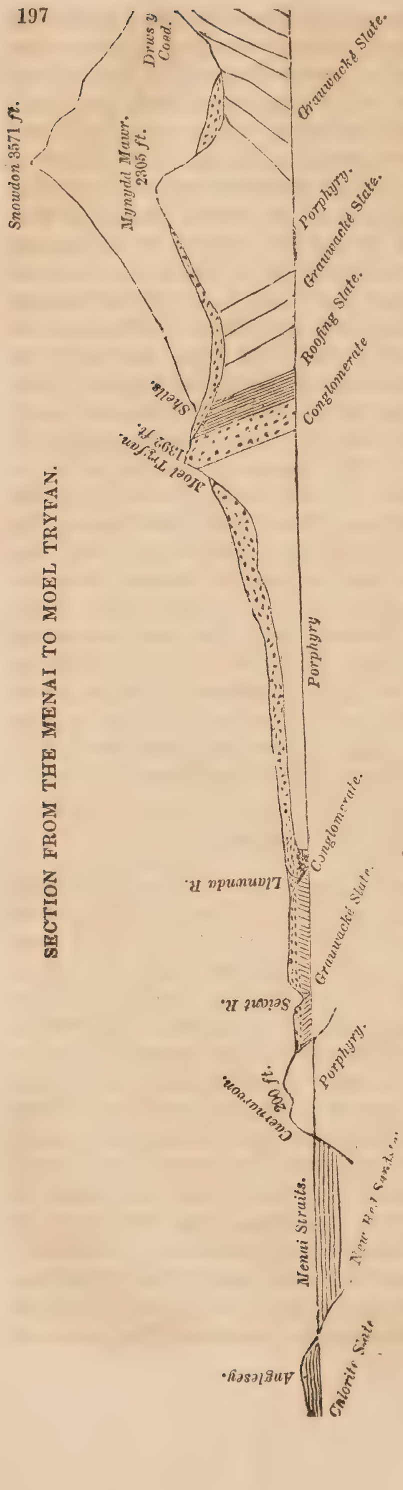

SECTION FROM THE MENAI TO MOEL TRYFAN.

jection is the absence of all proof (except the presence of marine shells) that the northern drift is a marine deposit slowly formed, such as would be found in the bed of any of our existing straits, if laid dry by movements of elevation. It contains neither marine incrustations, nor drilled pebbles, boulders, and rocks, nor layers of shells, nor groups of particular species, nor bivalve shells, with the two valves united.

We have discussed this question at greater length than our present limits will permit in a communication to the Geological Society of Dublin, to which we shall refer.*

Diluvial Deposits of North Wales.

Returning to the banks of the Dee, the same detrital deposits, with fragments of rocks derived from Cumberland, and marine shells, may be traced along the northern skirts of the Welsh mountains, by Chester, Holywell, St. Asaph, Abergele, and down the western flanks of that chain to the southwest extremity of Caernarvonshire. Granitic detritus gradually diminishes in quantity and size from the Dee to the Conwy, so as no longer to deserve the name of erratic blocks. In the district between the Menai and the Snowdonian chain, an area of seventy square miles, it becomes extremely rare; the detritus is chiefly local, and has descended from the Snowdonian mountains by the lines of existing drainage, though at higher levels than those of the present streams. Within this area fragments of granite have only been detected at eight points, and marine shells at four. One of these is near the summit of Moel Tryfan, which is 1392 feet above the sea, and distant from it between six and seven miles, both on the side of the Menai and of Caernarvon Bay. The shelly gravel of this spot has so often been spoken of in geological works as a raised beach as to render it necessary to repeat that it contains none of the characteristics already enumerated of a beach or sea-bottom. It rests on a layer, about two feet thick, of angular fragments of the subjacent rock. The shells and the fragments transported from a distance are collected in considerable abundance on one small spot near the summit, on the side exposed to the sea on the north. On its opposite slope granitic detritus becomes extremely rare, and marine shells are wholly wanting, and in two excavations on that side, only 1500 yards from the pit containing the shells, the mass consists of about twenty feet of angular fragments of the subjacent rock (slate is in one case, sandstone in another), covered by loam and sand, containing partially abraded felspathic blocks and pebbles, derived from the neighbouring summit of Mynydd Mawr, two or three of which are mixed with the mass of angular fragments. The diagram (197) represents a section of the country from the Menai to Moel Tryfan.

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* Journal of the Geological Society of Dublin, vol. iii. part 4.

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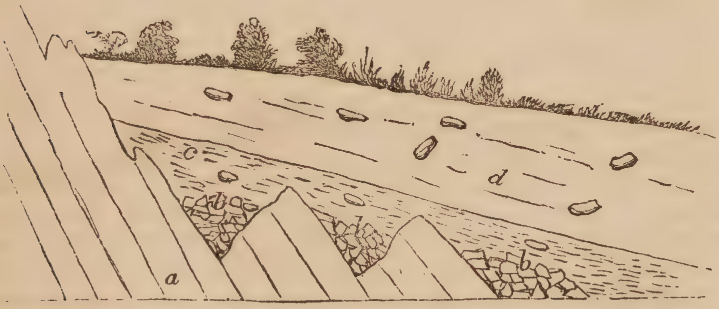

a. Rock, black slate at the base—chlorite slate at the summit.
b. Angular fragments of black slate.
c. Breccia, *en place*, composed of small angular detritus of black slate and chlorite slate, cemented by a loamy base—no shells.
d. Loam and sand, with partially worn boulders—shells.

The promontory which divides the bays of Cardigan and Caernarvon is covered with diluvial deposits of variable thickness, but frequently exceeding a hundred feet. They consist of sand, clay, and gravel, changing rapidly from one to the other, through which are dispersed broken marine shells, and amidst much local detritus, fragments derived from the north and west. Granite is rare, but they afford fragments of Antrim chalk, often very slightly abraded. The clay appears to agree in composition with the pebbly clay of Holderness, described by Professor Phillips, and is identical in character with that of the cliffs near Abergele, and of the opposite coasts of Ireland, differing only in those different localities in the nature of the fragments indicating distant transport.

The southwestern termination of this promontory affords several instances of the accumulation of the transported matter with shells, covering masses of angular detritus of the rock immediately subjacent, which may be supposed to have accumulated slowly under the atmosphere, after the manner of a talus, or to have been collected from the weathered surface of a bare rock by the first rush of the diluvial currents. The preceding diagram (198) represents one of these cases in Aberdaron Bay.

It has been contended that these angular masses may have been formed by movements of elevation, subsequently to the deposition of the transported matter; but this is most clearly disproved by a fact observable in the sea cliff at the base of the rock on which Criccieth Castle stands, where a narrow tongue runs off from the angular mass into the midst of the diluvial deposit.

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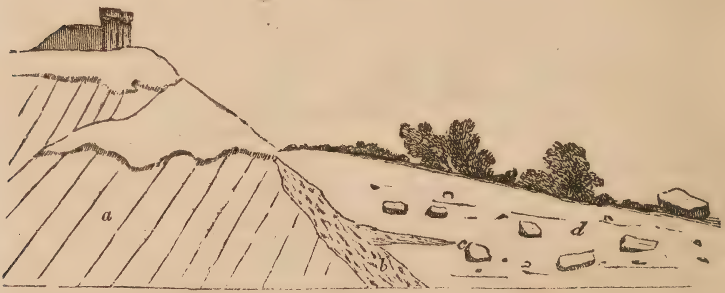

a. Quartz rock.
b. Ancient talus, composed of angular fragments of the above.
c. Tongue of angular fragments, running from the talus into the boulder deposit.
d. Loam, with boulders—no shells.

These accumulations of angular debris could never have retained their present character, if formed slowly beneath the sea. They must, in that case have been abraded and dispersed.

It is to be observed, that the upper or transported deposit in this section (199) contains no fragments of shells, though its base is washed by the sea. This is the general character of the deposit at the head of Cardigan Bay, where it is protected by the mass of the Snowdonian mountains from the sea on the north, and the detritus assumes a more local aspect, beingdestitute of granitic fragments; but the northern direction of an extraordinary current is still indicated by the presence of huge boulders derived from the Snowdonian chain. This circumstance appears inexplicable on the hypothesis of gradual submarine formation, but in accordance with that of great currents from the north traversing pre-existing land; and the local nature of the detritus of South Wales, observed by Mr. Murchison, of the Grampians, and other mountain chains, may probably be due to the same cause.

The Conchiferous Diluvium covers Mammalian Remains in Cefn Cave.

But the strongest evidence of the accumulation of this transported detritus on the surface of dry land, is to be found in Cefn Cave in the Vale of Clwyd, situated in a district overspread with detritus from Cumberland, and at a point which connects the erratic gravel of the eastern and western sides of the Cambrian chain.

The cliffs of carboniferous limestone which form the gorge of the Elwy, a little above its junction with the Clwyd, contain several caverns, only one of which has as yet been much explored. It communicates with the surface by fissures, and has an entrance from the face of the cliff, about one hundred feet above the river, and two hundred above the sea. The lowest parts yet examined, are about ten feet high, and are filled very nearly to the roof with sedimentary deposits, containing bones and teeth of the hyæna, bear, and rhinoceros. These are found in two strata, separated by a crust of stalagmite. The lowest is below the level of the entrance from the face of the cliff, and contains bones and teeth, enveloped in sediment, and mixed with smooth pebbles, like those of the adjacent river, and with fragments of wood.* It is covered by a crust of stalagmite, and above that, the cave is filled nearly to the roof with calcareous loam, containing bones and angular fragments of limestone, on the surface of which are sand and marl, containing fragments of marine shells, like those dispersed over the neighbouring district.† The sediment within the cave is generally finely laminated. This cavern has been compared, as we have already observed, to that of San Ciro; but they differ in these important particulars, that in the Cefn Cave there are no lithodomous perforations in the limestone, that the marine remains are confined to the upper part, and that the lower deposit of pebbles and bones is covered by a crust of stalagmite. This last fact, whether the cave was or was not a den of hyænas, proves that it was sub-aerial for a considerable time after the formation of the lower deposit, and before it was visited by a marine inundation. The marks of teeth on some of the bones, leave little doubt that the cave was inhabited by carnivora; and the identity of character which exists between the pebbles and silt below the stalagmite, and those of the river in times of flood, points to the river, when having a different relative level with respect to the cave, as the source from which they were derived.

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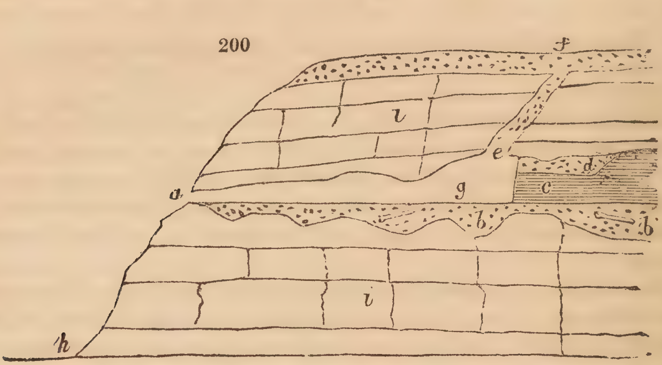
* Rev. E. Stanley, Bishop of Norwich. Proceedings of Geological Society, vol. i. p. 402.

† See a communication by the author to the Geological Society of Dublin, and the Proceedings of the British Association, Newcastle Meeting.



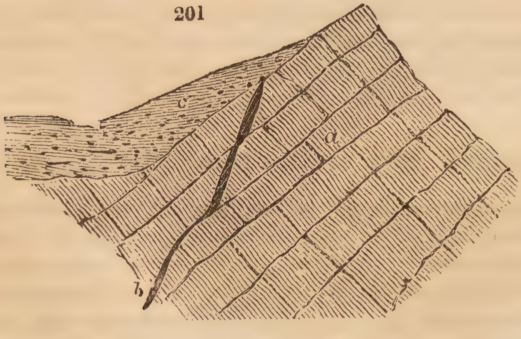
a. Level of the entrance of the cave.
b. Deposit of mud, covered by stalagmite, and containing bones, with rounded pebbles of grauwacke and limestone, and pieces of wood.
c. Mud, bones, and angular fragments of limestone.
d. Sand and silt, with fragments of marine shells.
e. A fissure communicating with the surface.
f. Northern drift spread over the surface of the country.
g. Portion of the cave cleared of mud.
h. River Elwy, 100 feet below the cave.
i. Limestone rock.

The upper deposit may, perhaps, be attributed to the waters of the river, pent back by the advance of the current, the close of which introduced the marine remains through fissures in the roof. The difference between the present levels of the mouth of the cave and the river, may be explained by erosion, both before and since the marine inundation, or it may be attributed to a movement of elevation, or to a combination of the two, erosion acting slowly while the surface was stationary, and with rapidity during the elevatory process. Dr. Trail considers that he has discovered proofs of this elevation, in the inclination of the laminæ of the sediment of the cavern, and their conformity to the dip of the beds of limestone. This fact escaped our notice, but the presence of drilled calcareous fragments in the lower part of the gravel-works of Talargoch Mine, near the mouth of the Clwyd, about five miles from the cave, may, perhaps, be deemed an indication of a raised beach, occurring at that point beneath the diluvial deposit.

Detrital Deposits of Talargoch Mine. At this mine a considerable quantity of lead was formerly extracted from a detrital deposit of great depth analogous to the stream tin-works of Cornwall, and it afforded a curious mixture of marine and terrestrial remains, bones and horns of deer and trunks of trees being associated with marine shells of existing species. The phenomena were not so closely examined as was desirable while the gravel-works were in activity, and being now discontinued, the mode in which the marine and terrestrial remains were associated is involved in much obscurity. The following facts, however, may be relied on. The upper part of the detrital deposit contains granitic fragments and broken marine shells, but no drilled calcareous pebbles, nor is the limestone beneath it perforated. The rubbish brought from the lower part of the gravel-works which contained the detrital lead, (often in masses weighing many tons,) has afforded fragments of marine shells, and rounded and drilled calcareous pebbles, mixed with many that are angular or slightly abraded. On the other hand, the bones of stags, derived from these works and mixed with marine shells, exhibit few or no marks of attrition. This is the only part of North Wales in which perforated pebbles have been found above the level of the existing beaches, and if there has been any local elevation at the mouth of the Clwyd the rocks of the vicinity must sooner or later afford phenomena corroborative of it: if, however, there be a raised beach here, it is quite clear that it is distinct in its characters from the transported detritus with shells.

The annexed diagram (201) represents the detrital deposits of Talargoch Mine.

201



a. Limestone rock.
b. Lead vein.
c. Detrital deposit, containing, in the lower part, shells, bones, and fragments of lead.

Conchiferous Diluvium of Ireland.

If from Great Britain we now turn to Ireland, we find it extensively covered with transported matter, indicating the action of powerful currents. The deposits consist chiefly of long narrow ridges or mounds, known by the provincial name of Eskers, and the direction of their longest diameters indicates that the currents proceeded, as in England, from the north and west; but other proofs of this are to be found in the distribution of fragments derived from particular quarters. The hard chalk of the county of Antrim is as easily identified in a heap of gravel as the granite of Shap Fell, and its original site is as well defined. Fragments of this chalk are dispersed in considerable quantities to the south, through the counties of Dublin and Wicklow and have very recently been found in Wexford by Mr. Griffith, and in Carlow, by Mr. C. W. Hamilton. They have also been borne to the eastward, and are found in smaller quantities both rounded and slightly abraded, but never perforated, in the clay cliffs of the southwestern extremity of Caernarvonshire already mentioned.

Dr. Scouler, who first discovered marine shells in the detrital deposits of the eastern coast of Ireland, has named them raised beaches;* but at the same time he identifies them with the esker gravel which, in the neighbourhood of Lough Neagh, he finds covering a lacustrine deposit; and having carefully examined with him the localities pointed out by him at Bray, Howth, and Glenismaule, we found them of the same character as the diluvial deposits of England and Wales, and destitute like them of every proof of slow accumulation. At Glenismaule the gravel is almost wholly composed of limestone, and here *two* perforated pebbles have been discovered; but they bear so insignificant a proportion to the mass, that they must be considered as drifted from the sea with the fragments of marine shells rather than as proofs of elevation. The gravel of the eskers of Ireland is generally spoken of as destitute of marine remains, but while we write, they have been discovered in these deposits in the county of Cavan, in the very centre of the island, by Mr. Griffith.

Diluvial Deposits of the Southeast of England.

Returning now to England, it appears from the descriptions of Dr. Buckland and Mr. Conybeare that the Midland Counties are overspread by diluvial accumulations containing detritus derived from the Welsh border, which has been drifted across the escarpments of the oolite and chalk into the valley of the Thames, in the same manner that the Cumbrian erratics have been borne into the valley of the Humber.

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* Journal of the Geological Society of Dublin.

Do these two drifts belong to the same or to different epochs; and if to the same, are they contemporaneous, or the effects of successive transient inundations acting during one short epoch? Their identity, after having been admitted on insufficient evidence, is now by some geologists denied, on evidence which appears equally insufficient. If we appeal to organic remains, we find that the marine shells of the diluvium are chiefly confined to the northwestern portions of England, while the mammalian remains are most abundant in the central and southeastern districts. It is probable, however, that many of the mammiferous deposits hitherto called diluvial are in reality lacustrine and fluviatile beds containing land and freshwater shells and *covered by diluvial detritus.* This is the explanation we are inclined to offer of the deposits of Cropthorne in Worcestershire. It is certainly the case with respect to those of the vale of London, where ossiferous gravel and loam, containing bones of the elephant, rhinoceros, hippopotamus, ox, and deer, associated with terrestrial and fluviatile shells all identical with species now inhabiting the neighbourhood, are confined to the vicinity of the Thames and its tributaries, and are overspread by loam and gravel rarely, if ever, affording mammalian remains, but containing fragments of far-transported rocks.

Two brick-fields at Brentford have yielded an immense quantity of these bones; one of them is situated about half a mile north of the Thames at Kew Bridge, and is twenty-five feet above the level of the river; the other is a quarter of a mile eastward of the Brent, near its confluence with the Thames, and forty feet above the river. In both cases the ossiferous deposits rest on the London clay, frequently with a thin layer of peat interposed, and are covered by the transported gravel which is spread over the elevated plain lying between the Uxbridge and the Colnbrook roads, and which, by an admixture of fragments transported from a distance, appears to have resulted from that current, the course of which from the Welsh border has already been alluded to.*

The Investigation of Diluvial Phenomena too much neglected.

The investigation of the diluvial phenomena of those regions best known to geologists, can as yet scarcely be said to have commenced; for a general explanation of them can only be safely based on a much more extensive accumulation of facts than we at present possess. The solution of the question, as far as regards the British Islands, would be a great point gained; but that cannot be expected for many years, while so few labourers appear disposed to apply themselves to this branch of inquiry, which at present is not a favourite subject with some of our leading geologists. It can only be effected by the combined exertions of many local observers. The determination of most of the necessary facts requires no great proficiency in geological knowledge. This is, therefore, an investigation to which we would invite young geologists; exhorting them to leave for the present disputed questions of geological dynamics, to exert themselves in the collection of facts, by a careful search in the gravel of their neighbourhood for detritus foreign to the district, and for fragments of marine shells, however small. It has been asserted, that they have not crossed the oolitic escarpment, south of the Penine ridge; and that, therefore, the poikilitic plain of Central England must have formed, up to a very recent period, the bed of a strait, dividing England from Wales. Here, then, an important inference is drawn from a negative fact, open to assault along a very extended line, and the discovery of a few well-identified pebbles of Cumbrian granite, or of a few fragments of recent marine shells in the gravel covering the watershed which divides the eastern and western drainage, will be a fact of great value in determining whether the detritus of the two sections of the island originated in the same or in different inundations.* When we have determined this point, we may then proceed to inquire whether the dispersion of northern detritus over England was contemporaneous with the transport of the Scandinavian boulders over the north of Germany, and whether this again was coeval with the distribution of erratic blocks outwards from the central regions of the Alps. Till these points shall be cleared up, and we shall have determined what regions were submarine, and what were converted into dry land, having nearly its present configuration when the erratic blocks were spread over them, it is a mere waste of time to speculate on the causes of these extraordinary currents, or to tax our ingenuity to explain diluvial phenomena by the operation of existing forces, acting with existing intensities.

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* W. K. Trimmer, in The Philosophical Transactions for 1812.

Recent Discovery of a Forest beneath Diluvium, by Mr. Lyell.

Since the preceding pages were written, an important advance towards the settlement of this question has been made in the separation, which Mr. Lyell has effected, between the diluvium under the name of drift and till, and the crag with which it had previously been confounded. From his recent examination of the coast of Norfolk, it appears that this drift, both stratified and unstratified, similar in character to that of Wales, Ireland, and Scotland, and containing Scandinavian boulders, covers an ancient forest and freshwater deposits of the newer pliocene era.

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* On the other hand, the transient nature of the watery action which transported the northern drift rests, in a great degree, on negative evidence, equally open to attack,—the absence of all those proofs of slow deposit of which every tertiary stratum affords instances. Why do not the advocates of long submergence produce some of these? They can find them in all other regular strata.

This subterranean forest establishes the fact, that on the eastern side of the island the drift or diluvium accumulated on the surface of pre-existing land, a fact which had previously been established on the western side by the phenomena of Cefn Cave. The grounds of controversy are thus reduced within narrower limits, and are confined to the means by which the drift was distributed, whether by one or more advances of the sea upon the land, or by the subsidence and long submergence of the latter. Mr. Lyell advocates the theory of gradual and long-continued submergence.* From some facts observed by ourselves in the interior of Norfolk, about thirty miles from that part of the coast examined by Mr. Lyell, we have been led to the conclusion that there are two diluvial deposits, the lowest of which must have acquired a certain degree of consistency before the uppermost was thrown down upon it, while from the very slight degree of abrasion which their component fragments have undergone, neither of them could have been subject to watery action of long continuance.†

The cliffs of drift near Cromer and Mundesley, exhibit most extraordinary and complicated bendings and tortuous foldings of the strata, which have not been observed in other parts of England. It seems impossible to explain them by forces acting from below, because they frequently rest on undisturbed and horizontal strata. They are referred by Mr. Lyell to lateral pressure from the grounding of drifted ice, on which he supposes the Scandinavian boulders to have been borne. For the transport of Scandinavian boulders, they may admit ice to bear the character of a *vera causa*, who deny its agency for the conveyance of Cumbrian detritus to Bridgnorth, and of Antrim chalk to Caernarvonshire, and it is a remarkable fact that these contortions in the diluvial drift should be confined to a locality where the erratics are traceable to an ice-bound region.

Should subsequent observations confirm the conjectures thrown out by Mr. Lyell on this subject, the number of alternations of contorted with horizontal strata, will afford a measure of the time during which the land remained submerged. The interval represented by each alternation will, of course, be shorter or longer, as we assume the ice drifts to have been an annual phenomenon, or to have occurred but once or twice in a century; and on the other hand, if but one or two such alternations can be found, it will be evident that there can have been but one or two drifts of ice bearing northern boulders to the shores of Newer Pliocene England. These contortions will also furnish us with a test of the value of some recent speculations as to the climate of that era; for if, as Dr. Beck and Mr. Smith, of Jordan Hill, suppose from the character of the shells of the red crag and the raised estuary deposit of the Clyde, they were formed under an arctic climate, their strata ought to exhibit similar contortions to those which, in the drift of Norfolk, are attributed to the lateral pressure of masses of ice pushing forward heaps of boulders, as in the Gulf of the St. Lawrence and the Baltic.

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* This question admits of an easy solution. At Brancaster, on the same coast, there is to be seen at low water a submerged forest, or peat bog, of a more recent era, (that treated of in the next chapter,) in which the substance of the peat, wood, and clay, abounds with perforations, containing the shells of pholas crispatus. The presence of similar perforations, in the subdiluvial forest of Mundesley, will prove its long continuance beneath the sea; their absence will be a strong argument in favour of the rapid accumulation of the diluvium.

† Proceedings of the Geological Society, vol. iii. p. 185.

CHAPTER XX.

Modern Group, separated from the tertiary series in England by the erratic block group—uncertainty of the point in the geological scale at which the human era commences—climate of the diluvial epoch.—Siberian elephant.—Post-tertiary lacustrine deposits of Yorkshire and Forfarshire—submerged forests—turf moors—preservation of human bodies in peat—blown sand—human skeletons in solid rock in Guadaloupe—river deposits—atmospheric action on rocks—erosive action of rivers in Auvergne—falls of the Niagara—sinuosities of rivers—river terraces—parallel roads of Glen Roy—excavation of valleys—deposit of river detritus on the land—valley deposits—deposits in lakes—delta of the Rhone in the Lake of Geneva—delivery of detritus into the sea—deltas of the Mediterranean.

MODERN GROUP.

The Erratic Block Group separates in England the Tertiary from the Modern Group.

To the modern group belong all those formations now completed, or in progress, upon the surface of the earth, or in its waters, which contain the remains of man and his works, or the remains of plants and animals of existing species, unmixed with any which are extinct. The separation of this, however, from the tertiary series, is by no means easy. In England, the erratic block group forms the point of departure: we have no human remains below it, we have no elephantoid remains above it. Some geologists deny the existence of any particular epoch characterized by the transport of erratic boulders, and though it may be conceded to them that every period of elevation has been accompanied by the dispersion of detritus caused by variations in the direction and intensity of oceanic currents, accompanying changes in the relative levels of land and sea, and though, in accordance with these views, the conglomerates of the old red sandstone, the molasse and the pebbly beds of the plastic clay may be classed as marine alluvia, yet in none of these are to be found those huge masses of transported rock, which impart to the superficial deposits of Europe and America the character of a boulder formation, and indicate peculiar dynamical agencies operating at a very recent period in the history of the earth.

In the last chapter, we traced the distribution of these large boulders from Cumberland southward to Brignorth, and eastward to the mouth of the Humber; we fixed the date of their dispersion by the marine remains of existing species which accompany them, both in Shropshire and Yorkshire; and we showed that in Denbighshire the same remains not only accompany the boulders in the superficial deposits, but have penetrated through fissures into a cavern where they are found in the upper part of the sediment covering the bones of mammalia. The dispersion of this detritus was, therefore, subsequent to the accumulation of the animal remains in the cave, and to the period when the district was inhabited by the rhinoceros and hyæna.

Mr. Lyell has since discovered similar proofs, as stated at the close of the last chapter, of the accumulation of diluvium, on the eastern side of England, on the surface of pre-existing land. Evidence of the same kind is afforded by the lacustrine deposits near Market Weighton, in Yorkshire. There a body of lacustrine marl twenty feet thick, covered by diluvial gravel, which forms part of the Cumbrian drift, and resting upon local gravel, was found to contain bones of the elephant, rhinoceros, and lion, of the horse, bison, and deer, all, or nearly all, of extinct species, under circumstances indicating tranquil deposit near the spots where they died, and accompanied by thirteen species of land and freshwater shells, identical with those now living in the vicinity.

In the valley of the Thames, a similar association of extinct mammalia with existing molluscs, occurs, as we have shown, beneath erratic gravel, likewise transported from the northwest; and though the dispersion of this last detritus is not yet proved to have been contemporaneous with the drift from Cumberland, yet, from the almost perfect identity existing between the two groups of organic remains buried beneath them, it is evident that they must have been formed during the same epoch. An erratic block period is thus established for England; but to that country the generalization must at present be limited, for the erratic phenomena of the north of Europe and of Switzerland are complicated with those of icebergs and glaciers, and their relation to the era of the bone caverns is not established beyond the fact, that in Denmark, the travelled boulders rest on strata containing exclusively existing marine shells, and that the osseous breccias of the south of Europe are associated with molluscs of existing species, sometimes marine, but more usually those of the land and fresh water.

Uncertainty of the point in the Geological Scale at which the Human Era commences.

But, even supposing the contemporaneous origin of all the diluvial gravel of Europe established, we have no evidence whatever whether its formation was prior or subsequent to the creation of man. That event may have taken place during any part of the tertiary era, when the presence of ruminantia, and other animals, so necessary to our comfort and convenience, affords a presumption that the earth was in a fit state for the reception of the human race. These became abundant during the older pliocene era, and though strata of that age are destitute of human remains in Europe and America, we must remember that the regions of Asia, nearer the birth-place of our species, are yet scarcely visited by the geologist. From the admixture, in certain caves, of human bones and implements, with the remains of extinct animals, it has by some been inferred, that man was an inhabitant of Europe while the elephant and rhinoceros "roamed the Celtic and Iberian waste." But in most of these cases, a careful examination of the circumstances under which the human remains are found, clearly proves their subsequent introduction, by the use of the cavern as a place either of abode, or of sepulture; and with respect to some caves in the south of France, where the proof is not so clear, the fact may be inferred from the nature of the weapons, ornaments, and implements, mixed with the animal remains. They are either Roman, or identical with those found in the Gaulish barrows of the neighbourhood, and in those barrows the remains of animals which have been interred with the human bodies belong to a distinct group from those of the caverns.

Climate of the Diluvial Epoch.

The evidence of organic remains as to the climate of the diluvial epoch, appears at first sight somewhat contradictory. We have the elephant, rhinoceros, and hyæna, in Europe, whose congeners are now confined to the warm regions of the earth; but they are associated with the remains of the stag, ox, and horse, as well as with shells marine, fluviatile, and terrestrial, which cannot be distinguished from the species now inhabiting the neighbourhood. On the whole, the presumption is in favour of a temperature not very different from that prevailing at present in the same latitudes, for we must remember, that those remains from which a contrary inference might be drawn, belong to *extinct species*, which may have been furnished with a covering, enabling them to sustain the winters of a northern climate. In the case of the fossil elephant, (elephas primigenius), so widely diffused over Europe, the north of Asia, and North America, we are certain that this was the case, from the singular discovery, in 1804, of an entire carcass, in a mass of ice, near the mouth of the Lena (lat. 70°), in so perfect a state of preservation, that when detached from the ice, its flesh was devoured by the bears. The skin was covered not only with thick bristles, from twelve to sixteen inches in length, but with reddish brown hair four inches long, beneath which was wool of the same colour, of the length of one inch. More than thirty pounds weight of this fur was collected from the sandbank on which the carcass fell from the icy cliff. The skeleton is now in the museum of St. Petersburgh, with many of the ligaments entire, and the skin remaining on the head. A carcass of a rhinoceros (R. tichorinus), similarly preserved, and furnished with a thick covering of hair, had previously been seen by Pallas, raised from the frozen soil on the banks of the Wiljui, a tributary of the Lena, in lat. 64°. The bones and teeth of elephants and other large mammalia, described by Kotesbue as encased in ice on the coast of North America, within the Arctic circle, appear, from the observations of Captain Beechy, to be in reality contained in cliffs of frozen mud, or sand, the face of which is covered with a thin coating of ice, and it is probable that there has been a similar error in the description of the circumstances under which the Siberian elephant was discovered.

All the lowlands of Siberia, from the shores of the Arctic Sea, to the mountains of Central Asia, contain tusks and teeth of elephants in such abundance, and in such a high state of preservation, that the fossil ivory is collected as an article of commerce. They are found, not in marshes and alluvial plains, but in high cliffs of sand and clay which form the banks of the rivers. It appears, then, on the one hand, the fossil elephant was furnished with clothing, adapting it for a residence in higher latitudes than the living species can inhabit, and on the other hand, that Siberia must have enjoyed a climate sufficiently temperate to have furnished a vegetation capable of supporting herds of the large mammalia which roamed its now frozen plains.

In the cases of carcases preserved from putrefaction in frozen sand or mud, we may be certain that the sediment in which they are enveloped, must have been soft at the period of their inhumation; we are equally certain that they must have been frozen very soon after their destruction, and must have remained congealed to the present time. It appears, therefore, that the change of climate affecting the Arctic regions must have taken place suddenly.

Some geologists consider that they have discovered evidence of a colder climate than the present having prevailed at the close of the tertiary epoch in the latitudes of Great Britain and Canada. We have already noticed the opinions of Dr. Beck, respecting the Arctic character of the shells of the crag. On an examination of some fossil shells, identical with existing species, collected by Captain Bayfield, from the most modern depoits near the Gulf of the St. Lawrence, Mr. Lyell finds that they agree more nearly with Arctic genera than those now inhabiting that locality, and resemble the fossil shells collected by him at Uddevalla, in Sweden, whereas, the shells now living in the Canadian and Swedish seas differ almost entirely. Mr. Smith, of Jordan Hill, has arrived at similar conclusions respecting the climate of Scotland, during the same epoch, from the character of the shells contained in the raised deposit of the basin of the Clyde. This is an important and interesting question, not to be decided hastily from an examination of the molluscs alone, but from the general aspect of the plants and vertebrated animals which accompany them.*

Post-Tertiary Lacustrine Deposits of Yorkshire and Forfarshire.

The diluvial deposits of Holderness are covered with numerous lacustrine deposits, which, amidst a great variety of details, present the following general arrangement in the descending order:

1. Clay of a fine texture, generally blue.
2. Peat, with roots of plants; and in large deposits, trees, hazelnuts, horns and bones of the ox and deer.
3. Clay of various colours, containing freshwater limneæ.
4. Peat.
5. Clay, with cyclades and other freshwater shells.
6. Shaly bituminous clay.
7. Laminated clay, coarse and sandy, filling hollows in the surface.

Of these beds the most constant are 1, 2, 3. Remains of the red deer are abundant; those of the Irish elk (cervus megaceros) which are rare here, are common in Ireland and the Isle of Man, in lacustrine marl, resting on the esker gravel, and covered by the peat bogs.

Mr. Lyell has described some lacustrine deposits in Forfarshire, which afford a marl, used for agricultural purposes, and which appear to belong to this epoch. The marl, which consists almost wholly of the exuviæ of molluscs of existing species, and contains subordinate masses of compact and sometimes crystalline limestone, rests on detrital deposits, is interstratified with sand, and covered by peat. The organic remains found in the marl, besides the freshwater shells, are the horns of bulls and stags, teeth of the wild boar, and, more rarely, the bones of the beaver. At the Loch of Kinordy, a skeleton of a stag was found in the marl, in an upright position; the points of the horns being near the surface of the marl, while the feet were two yards below it. In the peat covering the marl, other remains of stags have been met with, and also an ancient canoe, hollowed out of the trunk of an oak.

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* Proceedings of the Geological Society, vol. iii. p. 118. Mr. Smith appears to attach some importance, as an evidence of climate, to the abundance, in the raised deposits, of cyprina islandica, which he cannot find living in the Frith of Clyde. This species is very abundant on the opposite coast of Ireland, near the mouth of the Bann, and by no means rare on that of North Wales.

Submerged Forests.

Accumulations of peat and trees on the banks of the Humber, covered in some places by thirty feet of silt, like the "warp" now left by the river, may be considered nearly coeval with the lakes of Holderness. The occurrence of ancient forests or peat mosses between high and low water-mark, is a very general phenomenon on the tidal parts of rivers, and on the sea-coast, where they are exposed to view by artificial excavations, or by the shifting of the sand which covers them.

They occur on the shores of the Hebrides, of Lancashire, Cheshire, North and South Wales, and the counties of Devon, Dorset, Hants, Norfolk, Lincoln and York, as also bordering the Frith of Forth. In Ireland we have observed one in Youghal Bay, and Mr. De la Beche has described some on the coast of Normandy. Some of the accumulations of peat and trees near the mouths of rivers, which go by the name of submarine forests, may be drifted masses, like the raft of the Mississippi; but in most cases, the remains of stumps still rooted on the spot, leave no doubt that the trees have grown in situations which are now covered by the tide. The trees belong to species found in the inland peat bogs, and still indigenous to the island,—fir, oak, holly, yew, alder, birch, and hazel, the nuts of which occur in great abundance, together with the roots and leaves of aquatic plants. The present situation of these forests may in some cases be explained by encroachments of the sea arising from the shifting of a barrier of shingle; but the phenomena is of such general occurrence as to lead to the suspicion that it is due to some general contemporaneous action, and that a tranquil subsidence, like that which is now in progress on the shores of Greenland and Scania, followed those movements of elevation which accompanied or succeeded the transport of the diluvium. Horns of the stag are found in some of them, and Roman and Celtic weapons are said to have been met with in others. Should a re-elevation take place, the fact of their long submergence will be proved by the perforations containing the shells of pholades, which are frequently found in the substance of the peat and the trees.

Turf Moors.

Turf moors, or peat bogs, so common in the northern parts of the island, and which have been computed to cover one tenth of the surface of Ireland, mark the sites of ancient forests which have been destroyed by natural causes, or by the hand of man. Peat is composed chiefly of leaves and roots of plants, in a state intermediate between that of vegetable matter and lignite. It contain from 60 to 90 per cent. of matter destructible by fire, the remainder being an earthy residuum. A humid situation and a low temperature, which admits of vegetable decomposition without putrefaction, are essential to its formation; hence it is confined to the cold regions of the earth, is unknown between the tropics, and is rare in the valleys of Southern Europe. On the fall of a forest, the drainage of the atmospheric waters being choked by the trunks and branches of the prostrate trees, various aquatics spring up; among which the most conspicuous is a moss called sphagnum palustre, the upper part of which sends forth shoots, while the lower parts are decaying, and thus causes a rapid accumulation of vegetable matter. In most peat bogs, trunks of trees are found in considerable quantities, which it is evident have fallen on the place of their growth: 1st, Because the species varies with the nature of the substratum,—oak prevailing where that is clay, fir where it is sand; 2d, Because the largest trees are found in valleys, while they diminish in size with the increase of elevation; 3d, But, above all, because the roots are frequently met with in the substratum of clay or sand. Both in peat bogs and submerged forests, the trees often occur broken off at a short distance from the rooted stumps, and all prostrate in one direction. Their destruction may in such cases be ascribed to hurricanes. Instances are recorded of forests so destroyed in Scotland during the seventeenth and eighteenth centuries; and on the site of one of them, near Lochbroom, in Ross, the growth of the peat was so rapid that it was dug for fuel in less than fifty years.

Some of the forests which are now turf moors fell by the hand of man. It was part of the Roman policy to destroy the woods of the conquered countries; and to this cause may be ascribed some of the peat mosses of England and France. In Hatfield Moss, and others, Roman works and weapons have been found beneath many feet of peat. Many of the woods of Wales and Ireland were destroyed in like manner, after the English invasion of those countries, to prevent their affording shelter to the natives.

Preservation of Human Bodies in Peat. These, as well as animals, are frequently lost by being mired in bogs; and as peat possesses a peculiar property of preserving bodies immersed in it, arising from the antiseptic quality of the carbonic and gallic acids, or of the tannin contained in it, several instances have oc-occurred of human bodies thus immersed escaping decomposition for a very long time. The most remarkable are those of a woman, discovered at the depth of six feet in a moss in Lincolnshire, with antique sandals on her feet,—her nails, hair, and skin exhibiting scarcely any appearance of decay; and of a body, clothed in garments made of hair, which was found in Ireland, buried a foot deep in gravel, beneath eleven feet of peat. No bones of the elephant and other inhabitants of warm latitudes, which were so abundant in this country before the diluvial epoch, have been met with in any of our peat mosses. The remains are chiefly those of the stag, wild bull, and boar. The horns of the stag are not horns which have been shed, but those of animals which have perished, for they have portions of the skull attached.

Blown Sand.

The fatal effect of the sand storms to the traveller on the African deserts are well known. The sands of the Lybian desert, carried eastward by the prevailing winds, have reduced to sterility a large portion of the cultivated lands in Upper Egypt, and have buried some of the most splendid monuments of ancient Egyptian grandeur; among others, the celebrated temple of Ipsambul, explored by Belzoni. We have similar cases, though on a smaller scale, in our own country, of human remains and works of art buried beneath blown sand. In Cornwall, the sandy dunes thrown up by the wind on the coast have advanced inland, overwhelming ancient towns and villages; and among others, the Saxon church of Peranzabulo.

The advance of these sandy dunes on the eastern side of the Bay of Biscay has committed more extensive ravages; forests and lands have been destroyed, with many villages; and in the department of the Landes ten are now threatened, the sand advancing at the rate of from sixty to seventy-five feet annually.

By means of oxide of iron, or the infiltration of calcareous springs, these drifted sands are sometimes consolidated into a stone sufficiently hard to afford building materials, as at New Quay, and Crantock, in Cornwall.

Human Skeletons in Solid Rock at Guadaloupe.

The rock containing human skeletons at Guadaloupe, appears to be of similar origin. It constitutes an indurated beach between the cliffs and the sea, and is nearly all submerged during high tides. Two specimens have been brought to Europe, of which one is in the British Museum, the other at Paris. The matrix in which they are enveloped is extremely hard, consisting of minute fragments of shells and corals, cemented by calcareous matter. These fragments retain their colour, and some specimens of shells have been found in the stone, which have been identified with species of the neighbouring sea and land. This kind of rock is known to be forming daily, not only in Guadaloupe, but in most of the West Indian Islands.

River Deposits.

The study of deposits formed by rivers, including the general effects of running water on the land as a destroying and renovating agent, constitutes an important part of geological investigation. It makes us acquainted with the results produced by those forces of small amount which we see in daily operation, during periods, the duration of which we are able to estimate; and comparing these results with phenomena of the same kind exhibited in the older strata, we learn how large a portion of those ancient deposits has been produced by like forces of like intensity, and we are convinced of the immense lapse of ages which must have been required for their elaboration.

Rivers are the channels by which the waters of the ocean, raised by evaporation into the atmosphere, and falling on the earth, are returned to the ocean again. From the attraction exerted on the clouds by regions of elevated land, rivers usually have their source among ranges of hills, deriving their supplies either directly from the rains which fall on the hills, from the melting of ice and snow which cover their summits, or from water which, having been absorbed by, and percolating through porous strata, breaks out in the form of springs at lower levels.

In the upper part of their course rivers gather detritus, in the lower part they chiefly deposit it.

Atmospheric Action on Rocks. As soon as a river issues from its springs it begins to collect fragmentary matter, formed by the action of the atmosphere. This action is partly chemical. The hardest rocks are liable to disintegration from long exposure to the weather. By the gradual absorption of oxygen from the air, most mineral masses are reduced to an earthy incoherent state on the surface. Water likewise exerts a solvent power on the alkaline and calcareous constituents of rocks, particularly when it contains carbonic acid; and of this rain-water imbibes some from the atmosphere, while the water of springs contains a larger portion, given out from the interior of the earth. But the action of the atmosphere on rocks is chiefly mechanical. They are shivered by the lightning; large masses are detached by waterspouts and the violent rains of the tropics; the furrows on the surface of old buildings, and of some of the hardest rocks, attest the wearing effects of the less abundant and more gentle rain of our own climates. There change of temperature exerts a slow and silent, but constant and powerful energy in the process of disintegration. Water penetrates the pores and crevices of rocks, and expanding during congelation, acts with great force in overcoming the coherence of the parts, and its return to a fluid state is sufficient, with the aid of gravity, to remove the loosened matter. In Alpine regions, heaps of rocky fragments and earth, called *moraine*, skirt the glaciers where they have descended into the valleys, and display on a grand scale the power of frost in the formation and transport of detritus.

To these effects of the mechanical action of the atmosphere, we must add the landslips produced by springs, that is, by water which, after percolating a mass of porous strata, meets with a bed of clay, and is thrown out in the face of a cliff or at the bottom of a ravine. In its passage, it removes a portion of the argillaceous base, and large masses of rock being thus left without support, are precipitated into the valley below.

Erosive Action of Rivers. As soon as a river begins to collect detritus thus formed by the action of the atmosphere, it commences an erosive process on its bed and sides, from the grinding effects of the sand and gravel which it puts in motion. The size of the fragments transported depends on the volume and velocity of the current. The velocity is proportioned to the inclination of the bed, which is generally greatest near the source of the river, while as the velocity diminishes the volume increases from the influx of other streams. When several streams thus unite, instead of the collective waters spreading over a wider area, they contract into a column of greater depth, and the friction exerted on the fluid mass by the bottom and sides, thus becomes proportionally smaller. By this general law governing the action of running water, rivers flowing through level countries are enabled to scour their channels, and to prevent their being obstructed by the accumulation of sediment poured in by their tributaries, as the declivity of their beds diminishes.

Erosion of River Channels in Auvergne. Some of the rivers of Central France afford strong evidence of the erosive power of running water on even the hardest rocks. The valleys through which they flow have been obstructed by currents of lava poured into them, when the volcanos of that region were in a state of activity. Through some of the most recent of these currents of compact lava, channels have been excavated of considerable breadth, from twenty to seventy feet, and in some instances even to greater depths.

In a similar manner the Simeto, a river of Sicily, has cut a passage nearly fifty feet deep, and varying in breadth from fifty to many hundred yards, through a current of lava as compact as basalt, which is supposed to have been ejected from Etna so recently as the year 1603.

Falls of Niagara. The river which flows from Lake Erie into Lake Ontario, offers a striking example of the effects of erosion on softer strata. From Lake Ontario, which is situated 330 feet below Lake Erie, a low plain extends as far as Queenstown. At that point a table land commences, and continues for twenty-five miles to Lake Erie, whose surplus waters flow over this table land nearly on a level with those of the lake till they approach the falls; there, dividing into two sheets, the one six hundred, the other two hundred yards broad, they dash down a ledge of rock 160 feet in height, composed of horizontal strata of limestone resting on soft shale. The spray raised in thick clouds from this immense cascade, and driven by the wind against the shale, effects its constant and rapid disintegration, and the limestone being thus left without support is precipitated in large masses into the pool below. In this manner, the falls have cut their way back towards Lake Erie, fifty yards in forty years. Below the cascade, the current is contracted to the width of 160 yards, and rushes for seven miles through a gorge bounded by perpendicular cliffs. It is highly probable that the falls were once situated at Queenstown, where the table land commences, and that the excavation of this long ravine is the work of the river. At the rate of erosion observed at the falls during forty years, nearly ten thousand years would have been required for this operation; but the erosive process probably proceeded more rapidly when the whole stream was confined to one narrow channel.

Sinuosities of Rivers.

The tortuous windings of rivers are occasioned by impediments in their channels, arising either from the unequal hardness of the rock in which they are eroded, or from the accidental collection of alluvial matter. The stream is thus made to cross and recross the general line of descent, first impinging against one bank, and then, being turned off at an equal angle, striking against the opposite bank lower down. At each of these points it gradually works out a curve in the bank, while the debris not removed by the current accumulates in a promontory corresponding to the opposite concavity.

When the erosive process acting on a steep rocky bank, brings down a considerable mass at once, the talus formed at the base of the cliff becomes a barrier against further encroachment at that part, giving to the current a new direction, and throwing it against a point which had previously been little exposed to attack. Being thence reflected at an equal angle, it strikes the opposite bank at a new point, and thus the effects of the fall are felt, and a change of channel produced, along the whole course of the river below it. From these oscillations of the channel from side to side, it arises that narrow streams frequently hold a winding course through a wider and straighter trough of their own excavation, bounded by steep cliffs, every point of which has, at some time or other, been touched by the stream, the bottom of the trough being occupied by a low alluvial flat, which the river has formed during the process of erosion.

This low ground sometimes rises from the river in a succession of terraces, *c c*, fig. 203, which mark the different levels at which the stream has formerly flowed, and may be considered proofs of the elevation of the land analogus to the raised beaches on the sea-coast. The parallel roads, as they are called, of Glenroy, are two similar lines or terraces of shingle, which run round the valley at a considerable elevation, and are supposed to have formed the shores of an ancient lake, and to indicate the levels at which the waters successively stood, till the lake was finally drained by the destruction of its barrier. Such terraces of shingle on the shores of Lake Superior, in North America, occurring at various heights, extending to fifty feet, leave no doubt, as to their origin, for they contain shells of species still inhabiting the lake. The terraces of Glenroy are by some geologists considered marine beaches.

The tortuous flexures of a river, arising from the causes already mentioned, are sometimes so great, that for a time the stream returns in a direction contrary to its main course. The Mississippi, in some of its bends, makes a circuit of nearly thirty miles between two points, which are not more than a mile from each other in a direct line. The river, during freshets, sometimes bursts through the isthmus thus formed, and returns to the more direct line of descent.

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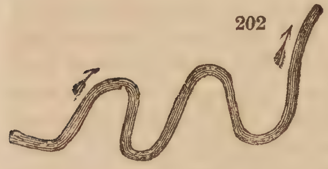
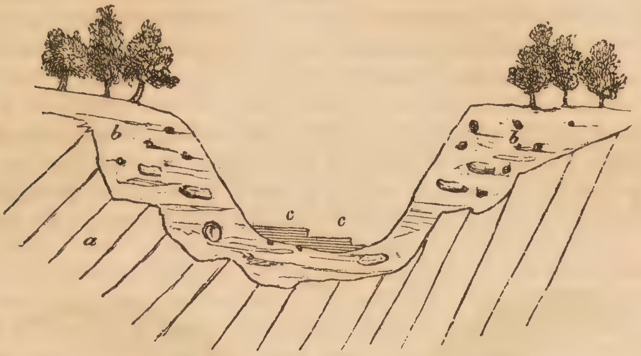


Such extreme sinuosities are not confined to rivers which, like the Mississippi, flow through alluvial plains: they are equally conspicuous in a part of the valley of the Moselle, sunk to the depth of from 600 to 800 feet, through hard transition rocks. In three places that river, after making a circuit of nearly seventeen miles, returns to within a few hundred yards of a former part of its course. The Meuse and the Wye afford similar phenomena.

Excavation of Valleys.

The origin of valleys has given rise to much discussion. By some geologists their excavation has been attributed to diluvial currents; others, with Mr. Scrope, contend, that though a sudden violent and transient rush of water might scoop out straight trough-shaped channels, it could never have produced winding valleys, like those of the Moselle and Meuse, the formation of which they attribute to the slow erosion of their respective rivers, and for proofs of the power of running water to excavate valleys they appeal to those of Auvergne, where the rivers have cut, not only through currents of lava, but through the solid rocks of subjacent gneiss. To these facts and arguments it may be added, that diluvial currents, so far from having been the excavating agents, have often choked up valleys with detrital masses. The annexed diagram represents a section across the lower part of Ogwen, near Bangor (203). We have there a previous hollow in the slate rock, *a a*, filled with a boulder deposit, *b b*, through which the river has excavated a trough to the depth of more than seventy feet without having cut through it. The valley of the Dodder, near Dublin, affords similar phenomena.

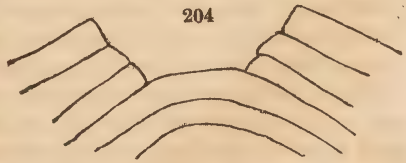
203



In opposition to those who contend that all rivers have formed their valleys, Mr. Conybeare* has shown that the erosive power of the Thames has, within the records of history, produced no effect whatever on the country through which it flows; that much of the water-worn gravel drifted through breaches opened in the sinuous line of its channel, is derived from rocks not found within the limits of its basin; and that the form of the country is the very reverse of that which would have been produced by fluviatile action, however long continued. Most of the valleys of England are of the same character.

It appears, then, that the excavation of valleys is not to be ascribed to any one general action, but it is a complex result of all the forces which have acted on the surface of any given region, both before and after its emergence from the ocean; and that we have several classes of valleys, in the formation of which different agencies have prevailed. The great valley of the Caledonian Canal is an oceanic valley, formed beneath the sea, and older than the conglomerates of the old red sandstone. There are longitudinal valleys, like those of the Alps, arising out of the line of junction of two formations. There are valleys of disruption, like some of the great transverse valleys of the same chain, produced by great upheaving forces; valleys of elevation (204), like that of the Wealden, Kingsclere, Pyrmont, &c., where the strata protruded and pushed up-

204



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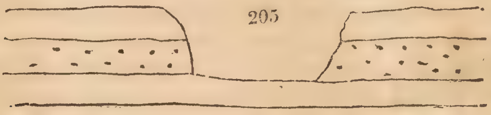
* Proceedings of Geological Society, vol. i., p. 560.

wards, dip in opposite directions from the axis of elevation; valleys of denudation (205), in which strata nearly horizontal, and once continuous, are now separated by a wide excavation.

205



Of these, some are simple, like the dry combes of the chalk (206), in which soft strata appear to have been scooped out by a retiring current during one period of elevation; others are of complex origin, referrible to several periods, and modified by various independent forces; and lastly, though rivers have not in general formed the valleys through which they flow, there are undoubted cases of valleys of erosion, deep gorges like those of Auvergne, excavated entirely by the long-continued action of the present streams.

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Detritus deposited on the Land.

Mountain torrents, whose course to the sea is short, hurry into it a confused mass of fragmentary matter, and there form deposits resembling some of the older conglomerates. Such are the streams which descend from the Maritime Alps into the Mediterranean. But longer rivers deposit their gravel and sand during the earlier parts of their course, and bear to the coast only matter so finely divided as to be capable of suspension in water flowing with moderate velocity. Some is arrested by lakes, some deposited by inundations on the surface of valleys and alluvial plains.

When a lake lies in the course of a river, it is evident that it will prevent the further transport of detritus till its basin shall be completely filled. The Rhone, which enters the Lake of Geneva charged with sand and sediment, deposits it all in that lake. In the same manner the Rhine is purified in the Lake of Constance, and most of the rivers which descend from the Alps part with their detritus to the lakes lying on the northern and southern flanks of that chain. In the course of time, when these lakes shall be filled up, they will present the appearance of level plains, traversed by their several rivers. The river may then cut through the rocky barrier which had confined the waters of the lake, and commencing its destroying action on the strata which it had formed, may convey them to lower levels, to fill up other hollows in the surface over which it flows.

Valley Deposits. Many level surfaces, traversed by a river, and surrounded by ranges of hills, may be mistaken for the sites of lakes, which are in reality valleys partially filled with detritus. The most gentle stream has its seasons of flood, during which is leaves sediment on the adjoining low grounds; a rapid river covers them with gravel, by frequently changing its bed. After having flowed for a time with sufficient velocity to transport gravel and sand, it reaches a part of its course where the declivity is less, and the consequent diminution of velocity compels it to part with the detritus with which it was charged. The stream obstructed by the matter deposited is diverted into a new channel, and being there again obstructed by the detritus brought down by the next flood, again changes its course, and thus wandering irregularly in its endeavours to seek the lowest level, covers a wide area with deposits of detrital matter. Such deposits will present a level surface, gently declining with the course of the stream, while a transverse section will display inclined laminæ of sand and gravel, sloping in various directions. When rivers flowing through level plains are confined artificially to prevent their devastating the adjoining lands, they have a tendency to raise their beds by the sediment which subsides. This is remarkably exemplified in the case of the Po, which having been thus confined for several centuries now flows along a mound of its own raising, which at Ferrara is higher than the roofs of the houses.

Lacustrine Deposits. In lacustrine deposits the lamination radiates from the point where the river enters the lake, and is inclined at a higher or lower angle, according to the depth of the lake. the volume of the river, and the size of the transported matter, When the lake is deep, and the detritus large in proportion to the propelling power of the stream, it will arrange itself in a conical form. When the volume of the stream and its transporting power are considerable, and the detritus finely divided, it will be diffused over a wider area, and a lamination will be produced more nearly approaching to the horizontal. The Lake of Geneva furnishes examples of both kinds of deposit. The matter poured into it in the summer, by the melting of the snow upon the Alps, has formed a delta which has advanced about a mile and a half in eight centuries, for Port Vallais, which was once on the edge of the lake, is now separated from it by a marshy plain of that extent.

The coarse detritus brought down by each successive inundation sinks soon after it enters the lake, but the finer matter, which may be seen settling in clouds through the clear water, is more widely diffused, and was found by Mr. De la Beche, by soundings, at the depth of ninety fathoms, and nearly two miles from the present mouth of the Rhone.

The deposits formed by the Drance, an impetuous torrent, which hurries in pebbles and sand, must be arranged at a high angle, as the same author found off its mouth a depth of eighty fathoms near the shore. A section of the delta of the Rhone would exhibit strata more than 600 feet in thickness, in which, beneath a surface levelled by the gradual advance of the river's mouth, there would be found beds of sand and gravel in curved and inclined strata near its commencement, clay diffused horizontally over the central parts, and thin deposits of the same fine sediment, thrown down during intervals of repose, would separate the coarser beds of the successive inundations.

The filling up of the lake will be effected by the meeting of the independent deltas of all the streams which enter it, in each of which the strata on a horizontal plan will be nearly concentric to the points of influx.

Deposit of Detritus in the Sea.

Such, then, is the action of running water on the land, constantly tending to reduce the inequalities of its channel to a uniform slope, by cutting down obstructions, and filling up hollows, and constantly moving detritus from higher to lower levels. The coarser fragments are generally deposited in the manner we have described, in the basins of lakes or in valleys, or spread over plains, but a vast amount of finely comminuted matter is held in suspension, till it reaches the sea, and is deposited where the tides and freshets meet, there to form new stratified deposits, charged with animal and vegetable remains, which in future ages may in their turn be reconverted into land.

The mode in which this detritus is delivered into the sea varies with local circumstances, depending on the volume of the river, the configuration of the coast, and its exposure to the influence of tides and currents. Rivers have been divided into two classes, according to the manner in which their sediment is disposed of on reaching the coast,—delta rivers and estuary rivers. If a river discharges its waters into an inland sea or land-locked bay, where the influence of tides and currents is feeble, most of its detritus immediately subsides, almost as it would in a lake; the course of the stream becomes choked, it divides into several channels, the coast line is advanced into the sea, and a delta is formed, the growth of which is more or less rapid, in proportion to the quantity of sediment brought down, and the depth of water into which it is delivered. Such rivers are the Rhone, Po, Nile, Danube, and many others. In the other class, to which belong the Thames, Garonne, St. Lawrence, and Maranon, the coast line extends into the land; an estuary, or negative delta, as it has been called, being formed by the joint action of the river and the tides.

The velocity of the tide is accelerated in its advance up an estuary by the narrower bounds into which a large body of water is continually forced. As it rises, it prevents for several hours the descent of the river, and causes it to accumulate in a pool, the waters of which, on the removal of the barrier by the fall of the tide, rush down with a force which they would not otherwise have possessed, and as the tide ebbs longer than it flows, the sediment held in suspension both by the salt and freshwater, is carried to such a distance beyond the mouth of the estuary, that very little of it returns with the next tide.

In situations where the velocity diminishes, from the meeting of conflicting currents, local accumulations of sediment form the marshes and sand-banks to be seen in most estuaries, but the preponderating force of the descending waters will tend to preserve a broad and deep opening. Most of the sediment will thus be delivered over to marine currents, and will be deposited on distant points of the same coast, or more widely diffused over the ocean, and, slowly subsiding, will cover its bed with fine-grained deposits, unmixed with sand and gravel.

Between the two extremes of delta and estuary rivers, there are many intermediate gradations, arising out of local circumstances. There are some rivers, like the Ganges and Niger, whose volume is so great during freshets, and their waters so turbid, that they deposit at those seasons a greater amount of sediment than the sea can remove during the rest of the year, and have thus formed the largest deltas in the world, on coasts exposed to high and powerful tides.

Deltas of the Mediterranean.

The Rhone having purified itself in the Lake of Geneva, is soon again rendered turbid by the junction of the turbulent Arve, charged with the detritus annually brought down by the glaciers of Mont Blanc; and receiving in its course, fresh accessions of sediment from the streams which drain the Alps of Dauphiny, and the primary district of Central France, it discolours the Mediterranean, for nearly seven miles from the point of influx. Over this space, in which the water deepens gradually from four to forty fathoms, fine sediment is thrown down in nearly horizontal strata, while the coarser matter is deposited near the shore. The head of the delta is at Arles, where the stream divides into two branches, as in the time of Pliny, but the base has advanced so much that the physical features of the coast no longer accord with descriptions of it written during the Augustan age. Places, too, which, were harbours in the ninth century, are now a league from the shore, and a tower erected on the coast so recently as 1737, is now a French mile inland.*

Currents raised by storms from the southwest frequently form bars across the mouth of the river, and thus separate considerable spaces from the sea, which either become freshwater lagoons, or, being subject to alternate irruptions of the river during floods, and the sea during storms, are converted into brackish pools, inhabited by a mixture of fluviatile and marine molluscs, generally of a stunted growth, and exhibiting considerable variations of form and colour from the type of their respective species. After such gales, the newly-deposited sandbanks of the river have been found covered with a layer of drifted marine shells. These facts are of importance, as elucidating the occurrence of similar alternatiyns in the older strata.

The Adriatic is rapidly filling with sediment poured by the Po, the Adige, and numerous minor streams, which descend from the Alps and Apennines into a tideless sea, running deeply into the land. Adria, from which the gulf received its name, is now about twenty miles from the sea, and for a hundred miles along the coast, that is, from the Gulf of Trieste to beyond Ravenna, accessions of land, varying in breadth from two to twenty miles, have taken place during the last two thousand years.

It has been observed, however, that the rate of increase has rapidly accelerated since the system of embanking the rivers, now become so general, prevented the diffusion of sediment over the land. The Po carries into the sea nothing but sand and silt, not transporting pebbles beyond its junction with the Mincio; but the rivers which enter the northern part of the gulf, bear into it considerable quantities of detritus, large enough to form coarse conglomerates.

From the researches of Donati, who dredged the bed of the Adriatic, it appears that the new deposits are not wholly mechanical, but consist in part of rock, formed of calcareous matter, incrusting shells—a fact in accordance with observations made at the mouth of the Rhone, and on the coast of Syria.

The delta of the Nile is small in comparison with the magnitude of the river, which is estimated to discharge annually 250 times as much water as the Thames. This arises, in part, from the small accession of atmospheric water which it receives in its passage through Egypt, and the immense quantity of far-transported detritus which it deposits in its valley; and in part, from the effects of a current which drifts the sediment eastward, and causes the rapid growth of new land on parts of the Syrian shore where no rivers enter the sea. M. Girard, one of the scientific men who accompanied the French expedition to Egypt, has even gone so far as to consider that the Mediterranean and the Red Sea were once united, and that the Isthmus of Suez is a mere bar formed by this current. The same author describes the mud deposited by the Nile, during its periodical inundations, as having raised the entire surface of Upper Egypt rather more than six feet since the Christian era. This fertilizing deposit consists of nearly one half argillaceous matter, one fourth carbonate of lime, the remainder oxide of iron, carbonate of magnesia and water. The Nile has, nevertheless, poured, and still continues to pour, a vast quantity of sediment into the Mediterranean, though we have no authentic records of the dates at which the delta was successively extended, by additions of habitable land. Its increase does not appear to have been great during the last two thousand years, though considerable changes have taken place in the base of the delta. Two only of its seven mouths remain, and the Lake Mareotis is silted up, while, on the other hand, others have been formed on the edge of the delta, by banks which the current before mentioned throws up.

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* See Principles of Geology, vol. iv. p. 432.

CHAPTER XVIII.

MODERN GROUP.—CONTINUED.

Delta of the Mississippi—drift timber—delta of the Ganges.—Tides—currents—their causes—currents of the Indian and Atlantic Oceans—action of the sea on coasts—waste of the Eastern coast of England.—Marine deposits—shingle beaches and sandy dunes—silted-up estuaries—submarine shoals connecting the British Islands with the continent—deposits of the Adriatic—their similarity to the Subapennine tertiaries—diffusion of sediment by marine currents.—Coral formations—their distribution—coral isles of the Pacific—Lagoon Islands.—Barrier reefs—indicate movements of depression and elevation.

Delta of the Mississippi. The Gulf of Mexico, into which the Mississippi has advanced an immense delta, may be regarded as a nearly tideless sea. This mighty river, which rises on the confines of the Arctic regions enters the sea near the tropics, having a course including curvatures, of about 5000 miles, and receiving as tributaries the Missouri, Ohio, Arkansas, and Red River, besides other minor streams. Its whole course, respecting which Captain Hall and Mr. Darby have furnished much valuable information, is fraught with instruction to the geologist; for, draining so large a portion of a great continent, on which man has as yet affected few changes, it exhibits the effects of running water on a scale of great magnificence, peculiarly adapted for comparison with the effects of river action, during periods anterior to the existence of the human race.

The breadth of the alluvial plain of the Mississippi below the junction of the Ohio, is from thirty to fifty miles, expanding lower down to nearly thrice that breadth. This plain is bounded by perpendicular cliffs, or "bluffs," sometimes as much as 300 feet high. With the exception of the Ohio, all the great rivers enter from the west; and, in consequence, the stream of the Mississippi is directed towards the eastern bluffs, which it is slowly but incessantly undermining. From the variety of climate traversed by this great river and its tributaries in so long a course, the freshets of its feeders take place at different seasons. When the Mississippi itself is in flood, it obstructs the current of the Ohio for a great distance; and in the same manner, a flood in the Ohio produces a stagnation in the upper part of the Mississippi. Considerable accumulations of sediment are thus formed at the mouth of each of the tributaries, which remain till they are removed by its own freshets.

From these causes, great changes are annually effected in the channel, independent of its general progress eastward. Extreme aberrations from the direct course are straightened, and new islands are formed; while others are swept away, or joined to the main land, by accumulations of trees and sediment. During inundations large portions of the alluvial banks, the deposit of former floods, give way, and several acres of forest are at once plunged into the stream. There the trees either become fixed in the channel, in the slanting position already described, when treating of the coal measures, or, accumulating in parts out of the general current, are formed into floating masses, known by the name of *rafts;* the rest are drifted onwards to the sea, and deposited amidst alternations of sand and mud. In 1808 it was estimated that the great raft contained 278,784,000 cubic feet; its breadth being 220 yards, its depth 8 feet, and its mean length 10 miles. This mass has accumulated in the space of fifty-two years, owing to some obstruction in the Atchafalaya, one of the branches by which the Mississippi enters the gulf, and which, from its position in a direct line with the main stream, receives a large portion of the annual drift. Similar accumulations, though of smaller extent, have formed in other parts of the Mississippi and its tributaries. In the Red River, rafts are composed exclusively of one species of tree,—cedars in some, pines in others.

From alternations of red sediment, peculiar to the Red River, with blue clay, characteristic of the Mississippi, which have been observed in the alluvial banks of the Atchafalaya, it has been supposed that it was formerly a continuation of the Red River, and that the two streams prevailed alternately in this channel before their final junction was effected.

The alluvial plain of the Mississippi is described as sloping gradually from the river towards the bluffs. During inundations the heavier particles subside near the banks, while the finely divided matter is carried to a greater distance, spreading a black unctuous deposit over the plain. The crests of the mounds thus formed constitute narrow strips of dry ground on each side of the river, separating its stream, as the waters begin to subside, from the inundated country. A long tongue of land, having exactly the same appearance, projects into the gulf at the mouth of the river, and forms a prominent feature in maps of the American continent. This tongue has advanced many leagues since New Orleans was built, and the whole coast is fringed with a belt of swampy uninhabitable country, extending over hundreds of square leagues. Numerous trees, carried into the sea during freshets, and covered with alternations of sand and mud, are forming submarine deposits, which spread far and wide over the gulf, and are filling it so rapidly that in many parts the depth of water does not exceed ten fathoms.

We cannot doubt that these deposits contain numerous bones of the inhabitants of the prairie and the forest,—the deer and the bison, the fox, the wolf, and the jaguar, together with the remains of tortoises and alligators, with which the waters abound. Neither can we fail to recognise in these alternations of argillaceous and sandy strata with masses of vegetable matter, a striking resemblance to the coal strata, accompanied by some points of difference. The resemblance consists in the mode in which the materials are arranged; the difference, in the greater amount of vegetable matter, and the absence of mammalian and saurian remains, which characterize the ancient strata.

Delta of the Ganges. The Ganges and Burrampooter constitute the channels of drainage for the waters which descend from the northern and southern slopes of the Himalaya chain, the loftiest mountains in the world, and they enter the Bay of Bengal together. The delta of the Ganges, exclusive of that of the Burrampooter, extends along the coast for 200 miles, and commences 220 miles from the sea, in a direct line. Its course is marked by numerous sinuosities, and its channel is subject to the same kind of changes that take place in the Mississippi. The influence of the tide extends as far as the head of the delta, when the river is low; but when its waters are swollen by the periodical rains, the ebb and flow are scarcely perceptible, except near the mouth, and the sea is discoloured by the turbid waters to the distance of sixty miles. It is during these seasons that the delta receives its greatest accessions. The deposits then formed are partially removed by the tides during the remainder of the year; but so great is the quantity of sediment, that the delta is continually advancing, notwithstanding the depth of the sea, which in the space of one hundred miles increases from four fathoms to sixty. The deposits consist of sand and silt; for the river ceases to transport pebbles at the distance of four hundred miles from the sea. Such soft deposits, when the diminished volume of the river permits the free ingress of the sea, are destroyed with great rapidity by tides which rise from thirteen to sixteen feet; old channels are filled up, new channels formed, and in one place a tract of land, 40 square miles and 114 feet deep, is said to have been removed in the course of a few years. On the other hand, the slightest obstruction, such as a sunken boat or a large tree, produces an accumulation of sediment, and causes the formation of a sandbank, which soon increases to an island, covered by a rapid growth of reeds, grass, and shrubs.

These islands, as well as the Sunderbunds, a wooded tract extending along the coast, and intersected by numerous creeks, rivers, and pools, abound with deer, buffalos, and tigers; and the waters and sandbanks swarm with gavials and crocodiles, the former confined to the fresh water, the latter sometimes ascending the river, but preferring salt or brackish water. Of crocodilean saurians there are three grand divisions, each characteristic of a distinct physical region: the alligator, or cayman, peculiar to America: the gavial, found only in India; and the broad beaked crocodile of the Nile and West Indies. It is to the long-snouted gavial, or Indian type, that the fossil crocodiles of the poikilitic and oolite systems have the greatest resemblance; those of strata more recent than the chalk resemble the broad-beaked crocodile of the Nile.

Of the magnitude of the deposits now in progress in the Bay of Bengal, we may form some idea from the statement of Major Rennell, that the Sunderbunds are equal in extent to the whole of the principality of Wales; and that some of the islands near the junction of the Ganges and Burrampooter, below Luckipoor, rival the Isle of Wight in extent and fertility.

The delta of the Niger is even larger than that of the Ganges, stretching more than 300 miles along the coast, and extending 170 miles into the interior.

Tides.

We will now proceed to the consideration of the destroying action exercised by the sea upon the land, and of the marine formations now in progress.

The motions produced in the waters of the ocean by tides and currents, however similar in their effects, originate in very different causes. Tides, it is scarcely necessary to say, arise from the attraction of the sun and moon. Their height and velocity are increased by the proximity of extensive lines of coast opposing obstacles to the free passage of the tidal wave. Among the small islands of the Pacific Ocean, remote from any continent, the rise of the tide is only two feet, and it does not exceed three feet at St. Helena. On any given coast it is subject to considerable local variations within short distances, being greatest where the stream encounters the greatest impediments from headlands, gradually contracting channels, and clusters of islands. We need not go beyond the coasts of our own seas for examples. Of the tidal wave from the Atlantic, a small part runs up the English Channel, flowing for a short distance to the north of the Straits of Dover; while the main body, moving more freely in an open sea, after passing the Orkneys, turns southward between Scotland and Norway, and runs with great rapidity down the eastern coast of England. This flood-tide from the north, as it is called, meets that from the south near the mouth of the Thames. The annexed diagram (207), wherein is marked the perpendicular rise of the tide on the opposite sides of the English Channel, shows how this is effected by the configuration of the coast. The excessive height at Guernsey, and between Jersey and St. Malo, is caused by the confinement of a large body of water between the Channel Island and Cape la Hogue; the water thus raised above the general level having no escape but through the channel between Alderney and the main land.

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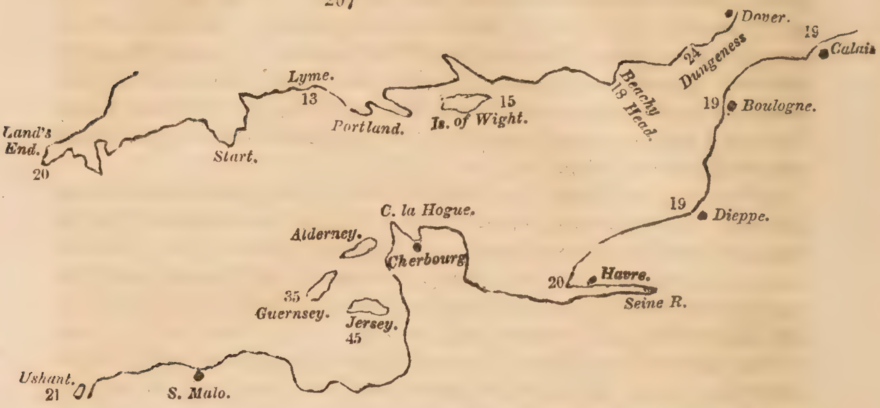

In the Bristol Channel a great rise of tide is produced by the gradual approach of the shores as it advances up the estuary. Thus at Padstow, near the entrance, it is twenty-four feet; at Lundy Island, thirty feet; at Minehead, thirty-six feet; at King's Road, near Bristol, forty-two to forty-six feet; while at Chepstow it occasionally exceeds fifty feet.

Estuaries of this form are subject to the tidal phenomenon called "the bore," a dangerous wave rushing up the channel with great violence, and terminating abruptly towards the land, like those waves which curl and break upon the sea coast. In the Severn this sudden rise of the tide frequently amounts to nine feet. In the Hoogly, one of the branches of the Ganges, the bore is of common occurrence; it commences at the point where the channel first contracts its dimensions, producing an instantaneous rise of five feet at Calcutta, and traversing a distance of nearly seventy miles, to Hooglytown, in four hours.

By reference to the last diagram it will be seen that the rise of tide at Dover amounts to twenty feet. Pursuing the line of our eastern coast northwards, the following local variations occur:—At the mouth of the Thames, seventeen feet, gradually decreasing towards Yarmouth, where it does not exceed seven or eight feet. At Cromer, it increases again to sixteen feet; at the entrance of the Wash, it is from twenty-two to twenty-four feet; at Spurn Point, nineteen to twenty feet; and at Flamborough Head, fourteen to sixteen feet.*

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* Lyell's Principles of Geology, vol. ii. p. 3. On the authority of Captain Hewett, R.N.

The local velocity of the stream of tide round headlands is in general proportioned to the body of water forced into the adjoining bays. In the Race of Alderney, the tide runs at the rate of seven miles an hour, gradually diminishing till the general level is restored. Round the Start, and the Bill of Portland it flows at the rate of four or five miles, which is double the velocity in the adjoining bays and at a distance from the shore.

The Orkney Islands, which oppose obstacles to the passage of the tidal wave, similar to the obstructions occasioned by the piers of old London Bridge in the water-way of the Thames, produce local currents of great rapidity. In the Friths of Ronaldsa and Stronsa, the velocity at spring tides amounts to five miles an hour. In the Pentland Frith, between the islands and the main land, it sometimes exceeds the rate of ten miles an hour.

The greatest recorded velocity of the tidal stream appears to be at the New Passage, in the Bristol Channel, and in the Straits of Magellan, where it runs at the rate of fourteen miles an hour.

Currents.

The tidal currents flow alternately in opposite directions, but there are permanent currents of the ocean, from 50 to 250 miles in breadth, and flowing constantly in the same direction. These are caused by the prevalence of particular winds, by the expansion and contraction of the water of the sea from heat and cold, and by solar evaporation.

The effects of the wind in producing a current are well known. It was ascertained by Smeaton, that in a canal, four miles long, the wind blowing along it raised the water four inches at one end; a prevalence of winds blowing from the ocean produces extraordinary tides in the British seas and harbours, and a continuance of gales from the northwest raises the surface of the Baltic at least two feet. In the open ocean, where there is no barrier to impede the progress of the water, instead of a rise a current is produced in the direction of the prevailing winds. Between the tropics these blow, during a great part of the year, more or less from the east, and consequently there is a general tendency of the waters towards the west.

Currents from the poles towards the tropics are produced by difference of temperature. Sea water increases in specific gravity as it becomes colder, not expanding when it reaches the freezing point like fresh water, and consequently, when its temperature is reduced at the surface, in high latitudes, it sinks, and warmer and lighter water rises to supply its place. By a continuance of the rising and descending currents thus produced, the lower parts of the sea, in high latitudes, become of greater specific gravity than those of the tropics at the same depths, and, unless prevented by the interposition of a submarine barrier, will move horizontally towards the equator, producing a superficial current of the lighter and warmer water in the opposite direction.

A powerful current, which commences 100 leagues from the Straits of Gibraltar, sets constantly into the Mediterranean. It is supposed to be caused by the tendency of excessive evaporation to reduce the waters of that inland sea below the level of the adjoining ocean; and similar currents must take place between two regions of the ocean which contribute in different proportions to the waters of the atmosphere.

A current once set in motion by these causes, separate or combined, and flowing from north to south, or from south to north, is subject to modifications from the rotation of the earth. In passing from polar to equatorial regions it will be continually advancing into latitudes where the rotatory velocity is greater than in those which it is leaving, and it will be deflected towards the west, or in a direction contrary to that of the earth's motion; while in passing from the equator towards the poles it will retain an excess of rotatory velocity over that of the regions into which it is proceeding, and will be deflected towards the east.

Currents of the Indian and Atlantic Oceans. The system of currents best known, is that which, commencing in the Indian Ocean, crosses and recrosses the Atlantic, under the various names of the Lagullas current, the South Atlantic current, the Equatorial current, and the Gulf stream.

Two currents, raised in the Indian Ocean, principally by the trade winds, and coming, the one from the open sea, the other down the Mozambique Channel, unite to the south of Madagascar. The united stream, 100 miles broad, runs down the southeastern coast of Africa, till turned westward by the great bank of Lagullas, off the cape of that name; it doubles the southern point of Africa and flows slowly along its western coast to the Bight of Benin (South Atlantic), then turning westward crosses the Atlantic to the coast of Brazil (Equatorial current), and runs northwest, parallel to the coast of Guiana, receiving in its passage the waters of the Maranon and Orinoco. After passing Trinidad it expands over the Caribbean Sea and the Gulf of Mexico.

There the pent-up waters are raised to a temperature 6° higher than that of the ocean in corresponding latitudes, and escape with great rapidity through the Straits of Florida, flowing northward along the coast of North America, nearly to lat. 44°, where they turn westward towards the Azores, covering the sea in the vicinity of those islands, over a space extending between 200 and 300 miles, from north to south, with water nearly 10° Fahr. warmer than the neighbouring parts of the ocean. The effects of the Gulf stream are sometimes felt in the Bay of Biscay, and a branch of it occasionally brings tropical wood and fruits to the shores of Iceland, Norway, and Ireland. One portion falls into the Guinea current, which runs southward along the coast of Africa to the Bight of Benin, and there, joining the Equatorial current, recrosses the Atlantic.

A current sets into the Polar Sea, through Behring's Straits, and two currents issue from the same sea into the Atlantic, the one between Greenland and America, the other down Hudson's Bay and Davis's Straits. This latter runs along the coast of America, as far as Newfoundland, bringing icebergs occasionally within the limits of the Gulf stream, which this Polar current there joins, taking an eastern direction to the shores of Europe and Africa.

Erosive Action of the Sea on Coasts.

The waters of the ocean are also affected by temporary currents produced by the action of gales of wind. The waves raised by such storms, when they break upon the shore, are the principal agents in the destruction of the land, and in the formation of detritus, which is transported and deposited at other points by tides and currents.

The waste of a coast is more or less rapid, according to circumstances, such as exposure to a wide expanse of sea, the nature of the strata, and the form in which they are exposed to the action of the waves. The configuration of a given line of coast indicates the nature of the component materials, hard rocks projecting in bold promontories, while deep bays are scooped out in soft and yielding strata, and at the weakest points, such as the junction of two formations. Even the hardest rocks are worn into holes and caverns by the battering of the surge and the grinding action of the sand and gravel with which it is charged. This process is greatly accelerated by the unequal hardness of different parts of the same rock, and by the joints, faults, and fissures by which they are traversed. The magnitude of the masses of rock moved by the waves when they break upon the coast during violent gales, appears astonishing, till we reflect that the specific gravity of the heaviest rocks is not more than thrice that of water, and consequently, that from their weight, as estimated in the air, we must deduct a third when immersed in a denser fluid. We have satisfactory evidence of blocks, varying in weight from two to seven tons, being drifted up inclined planes, during such storms, for the distance of one hundred, and even two hundred feet. The destructive action of the waves on rocks of equal hardness, is greatest, when they offer an abrupt front to it, and is the least on flat shores, where the breakers meet with no resistance, but spend themselves on the slope of a beach. When the coast is composed of stratified rocks, the dip of the strata towards the sea at a low angle, has the same effect in breaking the force of the surge.

The wear produced by the wintry storms, on even such hard materials as the granitic and schistose rocks, when exposed to the uncontrolled violence of an open ocean, is strikingly exemplified by the broken outline of the western coasts of Scotland and Ireland, studded with numerous islets, and penetrated by deep indentations. On the eastern and southern sides of England, consisting of secondary and tertiary strata, though less exposed, the waste is so rapid, from the softer nature of the materials, as to have become matter of record and observation, and to suggest the reflection how little such strata would be able to withstand the full fury of the Atlantic, if unprotected by the rocky barriers of Scotland, Ireland, Wales, and Cornwall.

Waste of the Eastern Coast of England. The whole coast of Yorkshire, from the Tees to the Humber, is yielding to the action of the sea. Its effects are considerable on the chalky and oolitic cliffs of Scarborough and Flamborough Head, which often rise to the height of three hundred feet, but the process of destruction is more slow than on the diluvial deposits of Holderness, composed of sand, clay, and gravel, which do not attain a greater elevation than one hundred and fifty feet above the sea. On this part of the coast, the sites of many ancient villages are now occupied by sandbanks, while the names have either disappeared from the maps, or have been transferred to situations further inland. At Owthorne, the sea advances at the rate of four yards in a year, and fears are entertained lest it should breach Spurn Point, and rushing into the Humber, devastate the rich marshes which border that river.

On the greater part of the Norfolk coast, the waste is equally rapid. At Hunstanton, the chalk cliffs, based on an arenaceous bed, are easily undermined, but the rock comes down in large masses, which, for a time, form a protecting barrier against the waves. The loss of land, here, is about ten yards in thirty years. At Sherringham, the low cliffs of chalk, covered with sand and gravel, lose about one yard in a year, but the rapid slope of the surface, from the sea, has lately caused a greater area to be removed in a given time, and seventeen yards disappeared between 1824 and 1829, at which date, there was a depth of twenty feet of water, where less than fifty years before there had existed a cliff fifty feet high. From Cromer to the mouth of the Thames, nearly equal havoc is produced on the tertiary and diluvial strata of sand and clay, and we have authentic records of the loss of whole manors and villages, with the greater part of the once populous borough of Dunwich.*

The southern coast is wasting at many points in a similar manner, and while we write, a meeting of land-owners is convened at Littlehampton, to devise means for preventing the encroachments of the sea.

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* For fuller details consult Lyell's Principles of Geology, vol. ii. p. 21.

Modern Marine Deposits.

The materials derived from the wasting land, are distributed by the agitation of the waves, according to magnitude and specific gravity ; the larger and heavier fragments remain upon the beach, till they are ground down to coarse sand, or are thrown up beyond the reach of the breakers ; sand is pushed forward by the tides, and finely divided argillaceous matter remaining longer in suspension is widely diffused by the action of currents; some is deposited in sheltered situations along the coast, where the agitation is less, and the velocity of the current diminished ; some is borne into the deeper recesses of the ocean.

Shingle Beaches, and Sandy Dunes. The breakers, themselves, in some situations, raise barriers against their own encroachments, by projecting shingles on the land, out of the reach of the retiring wave. The points favourable to the formation of shingle beaches, are low flat shores, protected on the sides by rocky points. Sand can be transported by currents whose velocity is insufficient to move shingle, but at the same time, it can be thrown upon the land by waves of smaller force, and when dry, is driven onward by the wind, and collected into hills, or dunes, held together by the creeping roots of the arundo maratima, or *marram.* These hills bar up the mouths of small rivers and estuaries, and form natural embankments for the protection of those rich alluvial flats which the tide deposits in every situation where its current stagnates.

Silted-up Estuaries. Our eastern coast afford several examples of the increase of land thus formed. The strait which separated the Isle of Thanet from the rest of Kent and was navigated by the Roman fleets, the broad arm of the sea, which during the Saxon era extended up the Yare to Norwich, and the estuary of the Ouse near Lewes have all been silted up within the lapse of a few centuries. The description given by Mr. Mantell, of these modern strata in the Lewes levels, indicates the several stages of the operation. At the depth of thirty-six feet, resting on detritus arising from the chalk, are beds, containing exclusively marine remains, among which has been found the skull of the narwal or sea-unicorn. These are covered by blue clay, containing a mixture of fluviatile and marine shells, showing that the water had become shallower and brackish, or alternately salt and fresh. On this again is blue clay, containing freshwater shells, only with the remains of deer, deposited when the shoaling was so far advanced that the river prevailed exclusively, and the water was no longer habitable by marine testacea. The next step was the formation of a morass, on which trees grew, or were drifted there by floods, for the clay is covered by a bed of peat, five feet thick, containing abundance of wood ; and lastly, this bog was converted into a meadow, by the silty deposit left upon it, by the occasional overflowing of the river.

These additions to the land have been effected entirely by the operation of nature; but the rich alluvial flat of Romney Marsh, and those which border the estuaries of the Humber and the Wash, formed in part of sediment brought down by the rivers, and in part of that derived from the wasting cliffs of Holderness, have been greatly extended by artificial embankments.

The fens of Lincolnshire lie chiefly below the level of the sea, which is still contending for the possession of them, and is only excluded by the skill of the engineer. From the evidence of the peat bogs buried beneath them, they appear to have once constituted a wooded tract, which became submerged, was partially embanked by the Romans, again inundated after their departure, and finally recovered and extended at various subsequent periods. The recent application of the steam-engine to the drainage of these fenny districts, has added considerably to their value; and it is now in contemplation to reclaim more than 200,000 acres of mud banks, on the borders of the Wash, which are at present covered every tide by about sixteen feet of water.

If we turn to the opposite shores,—to the "amphibious world,"

> Embosomed in the deep, where Holland lies,—

we see tracts far more extensive, won by man from the ocean, to which the ocean is re-asserting his claim. The whole coast line, from the Baltic to Ostend, has for many centuries been yielding to the force of the waves, which neither natural nor artificial barriers have been able to withstand. The islands on its borders have diminished in number and extent; rich and populous districts, protected by sandy dunes and costly embankments, have been overwhelmed, and marine bays have been extended far into the interior of the land. Of these irruptions of the sea, the most terrible were that by which the Bies Bosh was formed in 1421, and seventy-two villages destroyed, by the bursting of a dike, and those successive inroads during the thirteenth century, which swept away the isthmus between Steveren and Medemblick, and spread the expanse of the Zuyder Zee over the sites of towns, villages, and inland lakes.

So far, then, from these new deposits counterbalancing the destruction of the land, they can only be regarded as temporary acquisitions; the march of the ocean is still onward, its real contest is with the more solid strata which protect them; these are slowly, but incessantly yielding, and, deprived of their protection, the low alluvial districts will disappear with the utmost rapidity.

Submarine Shoals connecting the British Islands with the Continent.

On the other hand, the elevation of the bed of the sea, to the extent of 200 or 300 feet, would make a considerable addition to the area of the land, for the mean depth of the German Ocean does not exceed thirty-one fathoms, and the British Islands are connected beneath the sea with the continent, by a region of shoals, known to navigators by the name of "soundings," which commences at the bottom of the Bay of Biscay, and sweeps round by the western coast of Ireland to that of Norway. Throughout the greater part of this tract, the bottom may be reached with a line of eighty or ninety fathoms, and is found to consist of large banks, (the Dogger Bank is 345 miles in length,) intersected by deep and narrow ravines, with precipitous sides. These banks may be considered as inequalities in the rocky bed of the sea, produced during movements of elevation, and covered with the mingled detritus derived from the wasting shores of England and Holland, and the sediment discharged into it by rivers.

In some parts, the sounding line brings up small gravel, broken and drifted shells and corals, bones and teeth of fishes; but the surface of the banks consists in general of sand and mud, inhabited by various species of zoophytes and molluscs, and there can be no doubt that, if laid dry for our inspection, they would present a close analogy in mineral characters, mode of aggregation, and distribution of organic remains, to the strata of the crag. The principal difference would be, that the latter would yield a certain proportion of extinct species not to be met with in these recent deposits.

Deposits of the Adriatic. Donati found a similar resemblance between the deposits now accumulating in the Adriatic and the tertiary strata, elevated 1000 feet above the sea in the Subapennine hills. He ascertained that certain tracts were destitute of shells, and that in others, particular families were grouped together, while in some, again, a confused mass of shells, corals, and crustaceans of different species, were enveloped in mud, sand and gravel. In short, he found every variety in the distribution of organic remains observable in the secondary and tertiary strata. On the surface of the deposits he obtained living molluscs, or their shells, in a high state of preservation—for a foot below it they retained the ordinary character of dead shells—and at greater depths, they were completely mineralized and enveloped in solid calcareous tufa.

Calcareous springs, so prevalent in Italy, as well as other volcanic regions, feeding the rivers which enter the Mediterranean, or breaking out beneath its waters, will explain the presence of calcareous rocks among the sedimentary deposits. The marl of the Forfarshire lakes was converted, it will be remembered, into compact limestone, in the vicinity of the springs which fed them, and similar precipitates of carbonate of lime may be expected among the deposits of all seas, where the water receives a greater quantity of calcareous matter than is consumed by the testacea and polypifers in the construction of their habitations.

Diffusion of Sediment by Currents.

It is only at the mouths of rivers, near the shores, or in shallow seas like the German Ocean and Adriatic, that we can thus watch the progress of marine deposits, and ascertain their nature. What passes in the depths of the ocean must remain a mystery to us. Its mean depth is variously estimated at from one to five miles, and it probably contains profound abysses, in which no sediment is deposited, and which are rendered, by pressure and the absence of light, as destitute of life as the snow-clad summits of the Himalayas or the Andes.

Even from those parts of the oceanic bed accessible by the sounding line we are not yet in possession of all the information which might be obtained. The superficial velocities, as well as the directions of currents, require to be more accurately ascertained. Of the depth to which they extend we know scarcely any thing. Accurate information on these points would furnish data for reducing to calculation the distance to which particles of a given magnitude and specific gravity may be diffused by currents. That the fine detritus of the land may be transported to great distances, we learn from the fact observed by Captain Sabine, that the fresh and turbid waters of the Maranon affect the surface of the ocean for 300 miles from its mouth.

Coral Formations.

We might, likewise, obtain much more information than we at present possess respecting the habitats of marine plants and animals, the connexion of particular tribes, with the nature of the sediment, and the depths of water of which they are characteristic. Much light has recently been thrown on the nature and growth of coral reefs and islands, by the observations of Quoy and Gaimard, Stuchbury and Darwin. From the vast spaces occupied in the Pacific Ocean by coral reefs and small islands, with great and frequently unfathomable depths close to their sides, very erroneous notions had prevailed respecting the part performed by marine zoophytes, in adding to the stony matter of the globe. It was supposed that they raised these masses from the bottom of the sea, but it is now ascertained that they only inhabit water of moderate depth, and that the calcareous crust constructed by them is based on the summits of submarine mountains.

Distribution of Coral Formations. A high temperature is essential to the abundant developement of coral. It fringes the shores and islands of the Persian Gulfs, the West Indies, and the Indian Ocean, and abounds in those parts of the Pacific, included between the thirtieth degrees of north and south latitude. A great reef extends along the northeast coast of Australia for 1000 miles, with few interruptions, and for the space of 350 miles is completely continuous.

The Maldiva Islands lying in the Indian Ocean, to the southwest of Malabar, form a chain extending northwards for 480 miles, arranged in annular groups or *atols*, the longest diameter of some of which is nearly fifty miles; and the Laccadiva and Chagos Islands, lying to the north and south of these, are probably continuations of the same submarine ridge.

Of the lamelliferous corals, the only efficient agents in the formation of coral rock, the most common genera are astrea, meandrina, caryophyllia, porites and madrepora, and the depths at which they commence their operations do not, according to Stuchbury and Darwin, exceed fifteen or twenty fathoms, at which depths rocks may be seen through the calm and clear water destitute of living coral; below twelve fathoms, the bottom generally consists of calcareous sand, or of masses of dead coral rock. MM. Quoy and Gaimard state that astrea, which alone is capable of covering large spaces, is not brought up from water exceeding five fathoms, though branching corals live at greater depths. The line of lowest water at spring tides is the greatest height to which they build.

The coral banks of the Red Sea are only visible at low water, are of a square or riband-like form with tabular summits. The reefs of the Bermudas are described by Lieutenant Nelson as conforming to the shape of the rocky basis on which they rest. This is occasionally such as to produce belts of coral, inclosing spaces of tranquil water, the bottom of which is composed of mud resembling chalk, derived from the decomposition of the softer corals.

The reefs themselves assume a stratified form and consist of a mass of corals, calcareous sand, and drifted sediment, inclosing the remains of molluscs and crustaceans. In these reefs it is impossible not to recognise a resemblance to the coralline limestones of the oolites and other secondary strata, which is not quite so obvious in the coral rock of the Pacific.

Coral Isles and Reefs of the Pacific. In the Pacific and Indian Oceans coral formations appear under a variety of forms,—as flat and tabular islands, as fringes closely investing elevated land, as barriers protecting it at a distance, with an intervening channel of deep water, and either tretching along an extensive line of coast or encircling insulated points, and lastly, as annular reefs and islands, inclosing lagoons of shallow water These varieties may all be reduced to two divisions, each of which, according to Mr. Darwin, prevails exclusively over certain spaces of the Pacific, and marks alternate bands of elevation and depression; areas of elevation being proved by fringing reefs or by masses of coral and beds of shells occurring beyond the limits of high water, depression being deduced from the presence of encircling or barrier reefs and lagoon islands.

Lagoon Islands consist of circular or oval belts of coral, varying in breadth from 400 or 500 yards to one mile, and from two to 150 miles in circumference. This ring rising from two to five feet above the water, and covered with cocoa-nut and other trees, and having an abrupt descent towards the ocean, constitutes the habitable part of the island, and is broken by one or more deep channels, by which vessels may enter the secure harbour of the lagoon. The depth of water within the ring varies from twenty to thirty-eight fathoms, and the bottom is generally covered with the smaller and more delicate kinds of coral, the exterior of the ring, exposed to the serf, being occupied by the stronger species, which are continually extending the dimensions of the islands by raising their structures to the surface, ceasing to build only when they attain the line of low-water. The basis thus formed is covered, by the surf which breaks upon it, with fragments of coral limestone and calcareous sand, but for which the rock would be inundated during high tides. The islands of the dangerous Archipelago are of this description. The windward side of annular islands is generally the highest, and sometimes is the only part above the level of the sea, forming a crescent, occasionally wooded and inhabited, while the remainder is a mere reef, twenty or thirty feet under water. The same lunulate form prevails in those numerous sunken reefs, of whose presence navigators are only warned by the breaking of the surf, or by a few rocks rising above the surface. These reefs, like the lagoon islands, are highest on the windward side, gradually disappearing into deep water on the leeward side. It is also on the leeward side that the entrance into the lagoons is situated. Volcanic islands have generally a gorge on one side of the cone, which communicates with the sea, and the form of these lagoon islands has been supposed to be derived from the shape of the sunken craters on which they are based. The constant position, however, of the opening into the lagoon, on the leeward side, is not easily explained on the supposition of its being due to volcanic action. Circular islands and reefs, so numerous in the Pacific and Indian Oceans, do not occur in the West Indies.

Barrier Reefs. Encircling reefs surround elevated land at distances from the shore, varying from 100 yards to two or three miles, and have passages of entrance into the channel, like those of the lagoon islands. Most of the Society Islands belong to this class. The two islands of Raiatea and Tahaa are both included within one reef, having several channels, both on the windward and leeward sides. When the islands are large enough to supply rivulets, the breaks in the reef are generally opposite the points where the fresh water enters the sea, and renders it distasteful to the coral-building polypifers.

The great reef already mentioned as running for a 1000 miles nearly parallel to the northeast coast of Australia, furnishes a magnificent example of a linear barrier reef, and is considered by Mr. Darwin as the grandest and most extraordinary coral formation in the whole world. The reef itself, in each of these three classes of lagoon, encircling, and barrier, is closely similar, differing only in the absence or presence of neighbouring land, and in the relative position of the reef with respect to it. If, with Mr. Darwin, we consider them proofs of subsidence, Tahiti, or Otaheite, affords evidence of former elevation, for on the summit of its loftiest mountain, rising 7000 feet above the sea, there is a bed of coral, with an extinct crater, situated somewhat below it. It would appear likewise that the island had been thrown up by a sudden movement, for if it had risen slowly corals ought to be found growing round the edge of the crater, and on the slopes of the mountain. In the Mauritius a bed of coral is included between two currents of lava, and there can be no doubt that in the Pacific, where all the islands not composed of coral are volcanic, similar alterations are now in the course of formation. Among the islands visited by Captain Beechy, on his voyage to the Pacific, one named Henderson's Island was about five miles long, and one mile broad, with a flat surface, and bounded, except on one side, by perpendicular cliffs, fifty feet in height, composed entirely of coral, hardened in part into compact limestone. In many of the reefs of living coral, parts of the mass appear to have undergone this change, which must have arisen from the partial solution and re-precipitation of the calcareous matter. Henderson's Island appears to have been thrown up by one movement of elevation, as the cliffs exhibit no succession of terraces indicating a gradual rise. The depth of water, at a few hundred yards from the shore, exceeds 200 fathoms.

Lagoon and Barrier Reefs indicate movements of Depression and Elevation.

The circular and oval forms of reefs and lagoon islands were very generally supposed, till lately, to have arisen from their having been formed on the craters of submarine volcanos; and it is by no means improbable, that this has been the origin of some of the smallest of them; but in the case of the larger and less regular annular groups, such as those of the Maldivas, where we must suppose the craters fifty miles in diameter, the explanation appears by no means satisfactory; and the theory proposed by Mr. Darwin, which regards them as monuments of submerged land, including, as it does, every variety of structure, appears preferable. The annexed diagrams (208—210) represent land in three stages of submersion. In 208, it is a high island, surrounded by an investing reef of coral *c c*, which extends downwards, to the greatest depth at which the polypifers can live, that is about twenty fathoms. These, as the land slowly subsides, still keep the structure level with the surface *b b* (209), adding more coral (*c′ c′*) upon, but not within the reef, for those which grow in tranquil water are very different from those in the exterior, and less efficient in adding to the mass. Thus, while the portion of rock *a* has subdivided, the coral *c′* is formed, and we have an island, guarded by an encircling reef. As the subsidence continues, the rock becomes wholly submerged, the coral *c″* (210) is added, and a lagoon reef, or island, produced, the space between the coral

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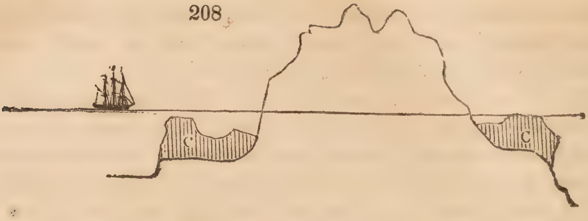
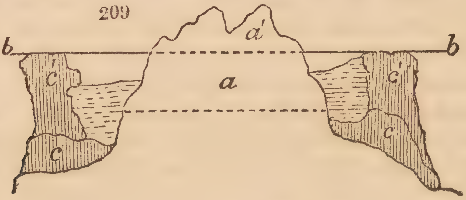
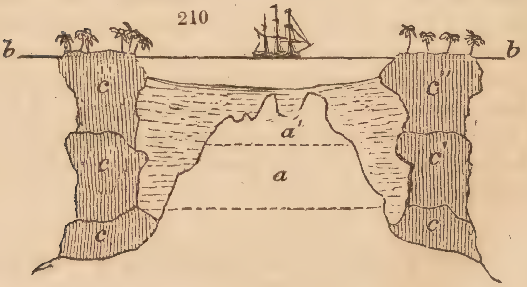


209

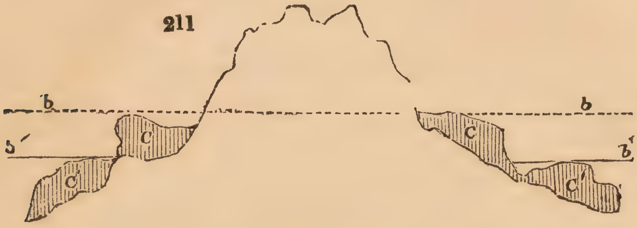


210



and the rock being filled by fragments of broken coral. In the same manner, a reef skirting a long line of shore would be changed into a barrier parallel to, but at some distance from, the land. Fig 211 represents the contrary process, in which, by the gradual rise of the land, the water level is shifted from *b* to *b'*, part of the investing reef is laid dry, and fresh coral, *c'* added on the outside.

211



In corroboration of these views, Mr. Darwin assures us, that there exists every intermediate form, between that of a well characterized encircling reef and a lagoon island, and urges the prevalence of certain classes in some parts of the seas which are never found in others, as a fact inexplicable, except on the theory of the configuration being determined by the order of movement.

The fact, which may be completely established, that coralliferous polypifers only inhabit water of moderate depth, is of considerable importance in reasoning on the circumstances under which the coralline limestones of the oolitic and other more ancient systems were formed. These, though now covered by many thousand feet of strata, must have been, at the time of their formation, within about twenty fathoms of the surface, and consequently the bed of the ocean must have undergone a gradual movement of depression, during the deposit of the superincumbent mass of strata. Independent evidence of such depression, as well as of subsequent elevation, has been offered in treating of the upper part of the oolitic rocks.

The gradual elevation and depression of the bed of the ocean in alternate bands during ancient geological epochs, analogous to that which appears from Mr. Darwin's observations to be now in progress in the Pacific, may be offered as an explanation of that alternation of developement in the rocks of contiguous systems, within a few hundred miles, of which the British Islands afford many examples. We may instance the thickness of the gneiss in Scotland, and the slight traces of it which occur in Cumberland, while the thinness of the Silurian strata in the same district, and on the western side of North Wales, where the older slate rocks are so largely developed, contrasts in a similar manner with their thickness on the English border. They again thin off rapidly to the south, while the old red sandstone in Herefordshire, and still more in Devonshire, swells out into a complex deposit. That rock again, thick in the south, almost disappears in Central England, and its disappearance is accompanied by a proportional increase from south to north in the mass and complexity of the superior millstone grit.

CHAPTER XXII.

MODERN GROUP—CONTINUED.

Geographical distribution of Active Volcanos—volcanic band of the Asiatic Isles—South American volcanos.—Insulated volcanos—difficulty of separating active from extinct volcanos—structure and mode of formation of volcanic cones—craters of Vesuvius and Etna.—Phenomena of eruptions—eruption of Shaptar Jokul—great eruption in Sambawa—of Jurullo.—Submarine volcanos—Isle of Sabrina and Graham Island—Von Buch's theory of craters of elevation.—Earthquakes—great earthquake of Lisbon—changes of level caused by earthquakes—recent elevation of the coast of Chili.—Extinct volcanos of the Eifel and Auvergne—mammiferous remains beneath lava currents—division of volcanos into antediluvian and postidiluvian—modern plutonic or hypogene rocks.

Igneous Rocks.

Geographical Distribution of Active Volcanos.

In our examination of the stratified rocks, we have noticed, associated with them, certain masses, to which geologists, by universal consent, now ascribe an igneous origin, and we have detailed the evidence on which, after much controversy, this conclusion has been attained. The British Islands afford no means of comparing these igneous rocks with the known products of subterranean heat, for though active volcanos are so numerous upon the surface of the globe, few of them are situated in countries inhabited by civilized man, and fewer still fall within the European area. The volcanos of the Italian shores are the nearest points at which we can witness the formation of pyrogenous rocks, and these have furnished the greater part of our information respecting the fused matter ejected from the interior of the earth. These products we can compare with the lavas which have flowed, in other parts of Europe, from hills whose volcanic origin is evident, though their fires are now dormant, and these again form an intermediate term, connecting modern igneous rocks with those of more ancient epochs.

Von Buch has divided volcanos into two classes, volcanos in line and central volcanos. The difference, however, is perhaps more apparent than real, for those of the Grecian Isles, Italy, and the Azores, classed by him as central volcanos, may be considered parts of a band,—less defined, it is true, than that of the Andes and Eastern Asia, but still less traceable from the shores of the Caspian into the Atlantic, for along this line, between 35° and 40° of latitude, volcanic vents occur at intervals, and it furnishes other indications of the action of subterranean fire, in the presence of hot springs, gaseous exhalations, and the earthquakes by which it is so frequently convulsed. In like manner, we may suppose a connexion to subsist between the volcanos of Iceland and those of Greenland. Central volcanos, moreover, are connected with axes of disturbance, and these, in the case of volcanos in line, appear to have determined the position of the igneous vents.

By far the greatest number of active volcanos are found in the Pacific and Indian Oceans, or on the shores of the continents which are washed by them.

Band of the Asiatic Isles. The most extensive lines of continuous volcanic action are those of the Andes and of the eastern coasts of Asia. The latter commences in the peninsula of Alaska, on the northwest coast of Russian America, in about 55° N. lat.; and crosses to the Aleutian and Fox Islands, and Kamtschatka. Thence it proceeds southwards by the Kurile and Japanese Islands, the Loo Choo Archipelago, the Philipine Isles, Mindanao, and the northeast extremity of the Celebes, to the Moluccas. Here a transverse line crosses it, one branch passing eastward by New Guinea, New Britain, New Ireland, to the New Hebrides, the Friendly and Society Isles, and other parts of the Polynesian Archipelago; the other, ranging westward, turns to the north with a gradual curvature through Java and Sumatra, and terminates at Barren Island, in the Bay of Bengal. Throughout the whole of this tract the effects of subterranean fire are exhibited on a most terrific scale. Most parts of it are agitated at intervals by tremendous earthquakes; some are scarcely ever free from slight vibrations. In the Aleutian Archipelago new islands were thrown up in 1806 and in 1814; the southwest extremity of Kamtschatka contains seven active volcanos: nine are known to have been in eruption in the chain of the Kurile Isles; in the Japanese group the eruptive vents are extremely numerous, and there, as well as in Formosa, earthquakes are frequent and violent. Sulphur Island is constantly emitting gaseous exhalations. An eruption took place in Mindanao, in 1764; Luzon contains three active volcanos; in Java there are thirty-eight, many of which constantly discharge smoke and sulphureous vapour. Sumbawa was devastated in 1815 by a dreadful eruption of the mountain Tomboro, in which the greater part of the population perished.

South America. Active volcanos are known to extend along the whole chain of the Andes, from Mexico to Chili, and are said to have been observed further north, in California, and further south, in Patagonia and Tierra del Fuego. They have all burst through basalt, trachyte, and porphyry. The highest part of the chain is in the province of Quito, where the largest volcanos, Cayambe (its summits crossed by the equator), Cotopaxi, Pinchincha, Antisana, L'Altar or Capac Urcu, and Tunguragua, all occur between the second degree of south and the third degree of north latitude. Cayambe rises to the altitude of 19,625 feet, in the form of a truncated cone. The eruptions of Cotopaxi, a perfect cone, 18,858 feet in height, are the most frequent and violent. In the provinces of Pasto, Popayan, Guatimala, and Nicaragua, between Quito and Mexico, no less than twenty-seven active vents occur in the space of five degrees of latitude. Mexico contains five active volcanos. The north and south line of eruption is here crossed by an east and west line, which connects it with the volcanic groups of St. Vincent and Guadaloupe on the east, and of the Revillagigedo on the west. If we now return to Quito, and follow the chain to the south, we find one point of eruption in Peru, and twenty-nine in Chili, forming mountains of great height. Villarica, one of the principal of these, is always burning, and may be seen at the distance of 150 miles. Several active vents are said to exist in Patagonia, and Captain Hall observed at a distance appearances indicative of a volcanic eruption in Tierra del Fuego.

The whole region from Cape Horn to New Madrid, in the United States, suffers severely from earthquakes. In Chili scarcely a year, in Peru scarcely a week, passes without a slight shock, and occasionally they are so violent as to cause the permanent elevation of extensive tracts, from one to twenty feet above their previous level. In Quito and Mexico the shocks are equally numerous.

In 1812, at the time of the great earthquake of the Caraccas, part of the basin of the Mississippi was violently convulsed for 300 miles, and New Madrid partly destroyed. The coast bordering the Caribbean Sea, and the whole line of its islands, are subject to tremendous shocks, while in Guadaloupe and St. Vincent's there are active vents.

Insulated Volcanos. The less continuous volcanic tracts, whose geographical extent is but imperfectly known, and which come under Von Buch's division of central volcanos, are those of Iceland and Jan Mayen's Land, of the Greek Isles and the shores of Italy in the Mediterranean; the Azores, Canaries, and Cape de Verd Islands, in the Atlantic; Madagascar and the Mauritius, in the Indian Ocean; Gabel Tor, in the Red Sea; the Sandwich, Ladrone, and Galapagos Isles, in the Pacific Ocean; Mount Ararat, on the borders of the Caspian; and according to Humboldt, an extensive volcanic area in Central Asia.

Difficulty of Defining the Limits between Active and Extinct Volcanos.

Although igneous rocks are associated with aqueous deposits of all ages, it is only among the tertiary strata that we meet with lavas which we can be sure were ejected upon dry land. There are found in certain districts of France and Germany conical hills of scoriæ and ashes, possessing all the characters of recent volcanos, but which cannot be proved to have been in a state of eruption within the historic period. These are commonly called extinct volcanos, but the term might, with equal propriety, have been applied to Vesuvius before the first century of the Christian era, when its fires again burst forth, after having been dormant from the remotest periods to which tradition extends. On the other hand, the lavas which alternate with the newer pliocene strata, composing the base of Etna, may have been contemporaneous with some of the eruptions of Auvergne and the Rhine. Where, then, are we to draw the line between active and extinct volcanos? The Isle of Ischia was the scene of volcanic eruption in those early ages when Vesuvius was quiescent, and for the seventeen centuries during which subterranean fire has found a vent in that mountain, Ischia, with one exception, has remained in a state of repose. In those continuous tracts of volcanic action which have been described, the different vents are in a state of alternate energy and quiescence; and this system of alternation probably prevails on a more extended scale. Regions of extinct volcanos, as they are called, invariably exhibit the feebler effects of igneous action,—gaseous exhalations, and thermal springs, maintaining for centuries an unvarying temperature,—and it is far from improbable that their now dormant craters may again awake to destructive energy.

Structure of Volcanos and their mode of Formation.

Volcanic mountains are composed of numerous alternations of scoriæ, ashes and stones, which have been ejected during eruptions, and falling around the central orifice have arranged themselves in conical layers, having an inclination of about 45°, determined by the angle of rest of the fragments. This mode of accumulation has frequently been witnessed in the formation of those minor cones which are thrown up from time to time in the vicinity of volcanic vents.

After repeated and violent earthquakes a chasm opens, great volumes of steam and gas are discharged, blocks of stone are projected into the air and shattered to fragments, melted lava thrown up in a similar manner is formed into scoriæ, or spongiform masses, by the sudden expansion of the entangled gases, or by the more violent effects of the same force is reduced to impalpable powder, and these falling near the orifice form conical layers, the gaseous explosions in the mean time keeping open a passage through the heap of fragmentary matter.

In this manner Monte Rossi, one of the minor cones on the flanks of Etna, 450 feet high, was formed in three or four months, and Monte Nuovo, in the Phlegrean Fields, rose to the height of 440 feet during a day and night. No streams of lava issued from these hills, but among the fragmentary layers of larger cones we find alternations of lava, which commonly bursts out at lateral apertures, and more rarely flows over the brim of the crater. These impart stability to the mass, which is further consolidated by other means. The ejected fragments which fall round the orifice are only partially cooled, or are subsequently acted upon by the heat and softened, so that they cohere, and vertical dikes of lava, radiating from the central aperture, traverse the cone and bind its parts more firmly together.

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The dimensions of the crater vary in different mountains, and in the same mountain at different times. During the intervals between great eruptions it frequently becomes nearly filled by the boiling up of lava from below, or by the falling in of scoriæ ejected from orifices which open on the sides or at the bottom. When an eruption takes place the accumulated mass is thrown out, and the resistance opposed by it to the passage of the elastic fluids sometimes causes a large portion of the old cone to be carried away by the explosion. In other cases, the escape of lava produces cavities, into which great masses of the sides are precipitated. By these two modes, variations are produced in the dimensions of the crater and the height of the mountain.

Craters of Vesuvius and Etna.

The crater of Vesuvius had been gradually filled in the manner above described between the end of the eighteenth century and the eruption of 1822, which produced a chasm of an irregular shape, about three quarters of a mile in its longest diameter. Its depth was at first estimated at about 2000 feet, but it was considerably reduced by subsequent explosions, which diminished the height of the mountain by about 800 feet.

Etna, very nearly 11,000 feet in height, and composed principally of matter thrown out by subaerial ejectments, is nearly circular, and about eighty-seven English miles in circumference. It is divided into three regions,—the *fertile* zone of cultivated country at its base; the middle, or *woody* zone, about seven miles broad, clothed with forests of chestnut, oak, and pine, intermixed with beech and cork trees; and the *barren*, or upper region, composed of bare lavas and scoriæ, where the cone, constantly emitting sulphurous vapours, rises from the midst of a small platform to the height of 1100 feet. On the flanks of the mountain, particularly in the middle regions, are numerous minor cones. There are above eighty of these of the largest class, some of which are from 400 to 700 feet in height.

During an eruption which took place in 1444 a large portion of the summit of Etna was truncated, and a crater formed, which must have been several miles in diameter. The cone was afterwards restored. Papandayang, one of the loftiest mountains in Java, lost nearly 4000 feet of its summit during an eruption in 1772, when a chasm was formed, in which an area, fifteen miles in length and six in breadth, was swallowed up. In Iceland, which is almost wholly composed of volcanic matter, there are some cones of scoriæ and ashes formed by successive eruptions from the same orifice, but in general the lava escapes by a number of low apertures, which are the channels for only one discharge.

Phenomena of an Eruption.

Indications of an approaching paroxysm are usually afforded by the numerous and violent earthquakes which convulse the neighbourhood of a volcano, often for many months before an eruption commences,—loud detonations are heard as the lava boils up in the crater; thick columns of vapour ascend from it; showers of red hot stones, and jets of liquid lava, are projected to great heights; and clouds of fine ashes darken the air, and are wafted by the wind to the distance of many leagues. At length a stream of lava pours out, sometimes over the edge of the crater, but more frequently from one or several lateral apertures, where the walls of the cone yield to the pressure and heat of the boiling column within. The mountain continues in a state of eruption for many months, in some cases for several years. The great eruption of Skaptar Jokul, in 1783, had not ceased for two years, and others have continued for thrice that time.

When first the lava issues from the mountain it is in a state of incandescence, "glowing with the splendour of the sun," and is nearly as liquid as water, but at a little distance from the orifice it acquires the consistency of honey. It soon hardens on the surface, and cracks into porous fragments, resembling scoriæ, while the interior of the mass continues sufficiently fluid to advance for several months after its emission. The bottom of the current is first retarded, and the central part gradually swelling out, falls down and is covered by more liquid lava from above; and thus the mass continues to move on, assuming the appearance of an immense heap of large and rough cinders, rolling over on itself, from the effects of a gentle impulse from behind. In this manner Mr. Scrope found lava, which had burst from Etna during the eruption of 1819, moving at the rate of a yard an hour, after the lapse of nine months, exhibiting in its crevices a dull red heat by night, and emitting copious vapours during the day.

Eruption of Skaptar Jokul. The great eruption of Skaptar Jokul before mentioned is remarkable for the volume of lava ejected. The current is divided into two branches, fifty and forty miles in length, and having an extreme breadth, the one of fifteen, the other of seven miles, the ordinary depth being about 100 feet. In ravines it was much deeper. The current from Etna, by which Catania was overwhelmed in 1669, flowed fifteen miles before it entered the sea, where it was 600 yards broad, and 40 feet in depth.

Great Eruption in Sumbawa. The most terrific eruption of which we have any record was that of the mountain Tomboro, in Sumbawa, in 1815, respecting which Sir Stamford Raffles collected so many interesting particulars. It commenced on the 5th of April, and had not entirely ceased before the end of July. The subterranean explosions which accompanied it were heard at the distance of 720 and 970 miles, and were mistaken for the discharge of artillery in a naval engagement. The ashes were blown to the distance of 300 miles in one direction, and 217 in another, and occasioned a darkness exceeding that of the darkest night. The East India Company's cruiser, *The Benares*, was involved in this darkness during a whole day, and the ashes continued to fall throughout the night, covering the deck in some places to the depth of a foot, and pervading from their lightness all parts of the vessel. At Bima, forty miles from the mountain, they fell in such quantities as to break in the roofs of the houses. A pint measure of them weighed twelve ounces and three quarters, and when mixed with water formed a very tenacious and adhesive mud. The sea was covered for several miles with a mass of floating pumice two feet in thickness.

This eruption was accompanied by a destructive hurricane, and by the usual agitation of the sea, which rose even when there was no wind more than twelve feet above its ordinary level, sweeping in great waves over the low grounds. The vegetation, on the north and west sides of the island, was entirely destroyed, and nearly twelve thousand of the inhabitants perished, partly from the effects of the hurricane and inundations, and partly from the gaseous exhalations which accompanied the eruption.

Jorullo. The eruption which produced the cone of Jorullo, in Mexico, derives importance from the confirmation it is supposed to afford of the theoretical views of Von Buch, respecting the commencement of volcanic action. This eruption took place in 1759, previous to which time the plain of Malpays, in which it is situated, was a fertile district, covered with fields of indigo and sugar-canes, and had not been visited by igneous outbursts since the discovery of America, though the presence of basalt, trachyte, and volcanic tuffs, on its skirts, afforded indications of their previous action. When Humboldt visited the spot in 1803 he found there six cones, composed of scoriæ and fragmentary lava, the least of which was 300 feet high, while the central and largest cone attained an elevation of 1600 feet above the level of the plain. From the base of these cones a convex mass extended on all sides, which was 524 feet high in the centre, and sloped gradually towards the plain, above which it rose, at the edges, thirty-nine feet.

The Indian accounts represented this convex mass, which covers an area of four square miles, as having risen up suddenly like a bladder during the eruption, which commenced in the month of June, and had not wholly ceased till the following February. It is described as accompanied, in other respects, by the usual volcanic phenomena,—earthquakes, subterranean noises, and the opening of a chasm, from which a vivid light was emitted, and clouds of ashes and fragments of rock projected into the air with great force. The neighbouring streams, Cuitimba and San Pedro, are said to have added to the violence of the eruption by the decomposition of their waters, which were engulphed in the fiery orifice; and eruptions of mud and of clay, enveloping balls of decomposed basalt, appear to confirm this account, and to prove that subterranean water performed an important part in producing the convulsion.

At the time of Humboldt's visit the convex protuberance was still in a heated state, and was covered by numerous conical mounds or "hornitos," (little ovens,) from six to nine feet high, which emitted clouds of steam and sulphuric acid. The heat has since gradually diminished, and the surface is returning to its former state of fertility.

Submarine Volcanos.

Several instances are recorded during the last century of volcanos rising through the sea, and producing new islands; most of which being composed of loose materials soon disappeared, leaving only shoals to mark their site. One of these volcanic islands was formed on the coast of Iceland during the eruption of 1783, and another in 1830. In 1806 and in 1814 new conical islands arose in the Aleutian Archipelago, which appear to have been composed of solid lava, as well as scoriæ, since they did not again subside below the level of the sea. The first is described as four miles in circumference; the latter as having a peak three thousand feet high. But the two cases respecting which we have the most accurate information, are those of the islands thrown up off the Azores in 1811, and on the coast of Sicily in 1831.

Isle of Sabrina. The first was witnessed by Captain Tillard, of *The Sabrina*, who named it after the frigate which he commanded. The eruption commenced with columns of black scoriæ, thrown up to the height of 700 or 800 feet above the sea, accompanied by violent explosions and repeated flashes of lightning. During the intervals between the discharges, a great body of vapour revolved almost horizontally over the spot. In the course of a week an island was formed, nearly a mile in circumference, and 300 feet high. When Captain Tillard landed upon it, he found a crater in the centre, filled with boiling water, and communicating with the sea by a lateral gorge. The island very soon disappeared.

Graham Island. The equally short-lived island, which rose more recently in the Mediterranean, received no less than seven names. Sciacca and Graham Island are those which have been most generally adopted. It was situated in latitude 37° 11′ North longitude, 12° 44′ East. A few years before the eruption, a depth of more than 100 fathoms existed on the spot. Towards the end of June, 1831, Sir Pulteney Malcolm in passing over it experienced concussions like those of an earthquake as if his ship had struck on a bank. In the beginning of July, some Neapolitan vessels reported a violent ebullition of the sea, and the emission of columns of smoke and vapour; about a week afterwards, a small island was elevated twelve feet above the sea, with a crater in its centre filled with boiling water of a dingy red colour, and ejecting volcanic matter; the surrounding sea being covered with dead fish and floating scoriæ. The diameter of the crater was at that time estimated by Captain Swinburne at seventy or eighty yards, and it had an outlet on the side by which the boiling water escaped. The eruptive phenomena were nearly similar to those observed off the Azores. Columns of steam, accompanied by discharges of scoriæ and dust, were thrown up to the height of several hundred feet, a loud roaring noise, and the formation of a vast quantity of steam, accompanying their rise and their fall into the water; while forked lightning, followed by thunder, darted in all directions within the column, which was darkened by dust, and distorted by gusts and whirlwinds. Most of the stones ejected were less than a foot in diameter.

On the 3d of August, when Captain Senhouse landed on the island, the crater was about 400 yards in diameter, and the island a mile and a quarter in circumference, and 160 or 180 feet high. It shortly after attained its greatest dimensions; the circumference being estimated at nearly 3 miles, and the height at 200 feet; after which it began to diminish by the action of the waves. Towards the end of October the crater had disappeared, and the surface of the island was reduced nearly to the level of the sea; and about the end of 1833 the only vestige of it was a dangerous shoal, consisting of black stones and loose sand, with a solid rock in the centre, composed most probably of lava which had cooled within the crater. A second shoal occurs at the distance of about 180 yards to the southwest, where a minor eruption had been observed in August, 1831.

It is obvious from the above description that the fragmentary matter ejected during submarine eruptions will not be arranged in a succession of conical layers, as in eruptions of subaerial; but being more widely diffused by the agitated waters, will form a solid tufaceous mass, derived from boiling red mud, and enveloping scoriæ, stones, fishes, and marine shells.

Von Buch's Theory of Craters of Elevation.

The origin of volcanic rents has been a subject of much controversy. It is true we have seen the rise of volcanos through the sea, in the manner above described, and the accumulation of subaerial cones, like those of Monte Nuovo and Monte Rossi; but these, and even the eruption of Jorullo, can only be regarded as the reopening of old vents in regions which have long been the theatres of subterranean fire. The commencement of its action in new regions has never yet been witnessed by scientific observers.

It is by no means uncommon to find volcanic islands, composed of trachyte and other igneous alternations, dipping outwards in every direction, and surrounding a central cavity, resembling an enormous crater, towards which they present a steep escarpment. There are various modifications of this general form. In Palma, one of the Canaries, this central cavity is 6 miles in diameter, and 2000 feet above the sea; and the surrounding ridge is intersected by a gorge running down to the coast, and making a section of the beds which are shown to consist of tuff alternating with basalt and resting on conglomerates composed of granite and quartzose fragments. The escarpments which surround the cavity are traversed by dikes of lava, like those which are seen in the craters of Etna and Vesuvius. The volcanic peak of Teneriffe rises out of a similar valley, bounded by cliffs of the same nature, from 1000 to 1800 feet high.

Barren Island, in the Bay of Bengal, consists of a circular ridge of steep volcanic rocks, surrounding a basin filled with the waters of the sea, with which it communicates by a chasm, resembling that of the Isle of Palma. In the centre of the basin a volcanic cone, in a state of activity, rises to the height of about 1700 feet, which is that of the encircling ridge. In the Grecian island of Santorin, the basin consists of a nearly circular gulf, about six miles in diameter, the inclosing ridge being broken into three segments. Two-thirds of the circuit are composed of the crescent-shaped Isle of Santorin, the remainder is made up of the isles of Therasia and Aspronisi, the former of which was separated from Santorin by an earthquake 233 years before the Christian era. Instead of one, there are thus three entrances into the basin; in the centre of which rise two small volcanic cones, with craters,—Micra Kameni raised by successive eruptions in A. D. 1573, and Nea Kameni thrown up A. D. 1707 and 1709. Besides these it contains the small island of Palaia Kameni, a mass of lava, which appears to have been upheaved without eruption 196 years B. C.

Palma, Teneriffe, with other neighbouring islands, as well as Barren Island and Santorin, are called by Von Buch *ehrebungs cratere*, or craters of elevation; and he supposes them to be the result of intumescence of the earth's crust, softened by internal heat, and expanded by the force of elastic vapours into conical or elliptical masses, with a central cavity through which the gaseous matter escaped.

This hypothesis has been warmly controverted by Mr. Lyell, who considers the so-called craters of elevation as but the truncated portions of large cones, formed by the accumulation of ejectments from a central orifice, the upper parts having been removed by the action of the waves and by gaseous explosions; and he has adduced some very strong arguments in support of his views. In the first place, the arrangement of the layers of volcanic matter is precisely that which prevails in cones known to have accumulated by the ejectment of fragmentary matter,—a mode of formation of which we have daily examples, while we have none of a crater of elevation. It appears likewise that when stratified rocks, containing organic remains, have been elevated with volcanic rocks, they do not partake of the quâquâversal dip of the latter, but retain their original horizontality. The destruction of the summits of Etna and Papandayang before mentioned, produced craters, it is contended, as large as those called craters of elevation; and we find the counterpart of the lateral gorges in the openings by which the craters of submarine volcanos, composed of ejected fragments, communicate with the sea.

The strongest arguments adduced on the other side are, the analogy of the circular and elliptical valleys of elevation formed by the upheavement of stratiform rocks, and the rise of the plain of Malpays, which rests entirely on the authority of Indian observers.

Earthquakes.

These convulsions of the crust of the earth may be regarded as a more violent and general effect of the same cause, whatever it is, which produces volcanic eruptions. Their greatest intensity is confined to particular tracts, which are likewise, as we have shown, lines of eruptive vents. They generally give warning of an approaching volcanic erruption by shocks, repeated for some time, and increasing in violence, till a discharge from a neighbouring orifice relieves the accumulated pressure, and restores the internal equilibrium. The resuscitation of the long dormant fires of Vesuvius, was preceded by convulsive movements, which shook the neighbourhood of Pompeii from A. D. 63 to A. D. 79. They are sometimes connected with more distant volcanos. The great earthquake which destroyed the Caraccas on the 26th of March, 1812, was followed in about a month by an eruption of the Souffrier, in St. Vincent's. The feebler effects of these subterranean movements extend to countries remote from centres of volcanic excitement. These may be regarded as vibrations propagated laterally through the crust of the earth, in the same manner that sound is transmitted through the atmosphere, extending over vast areas, not instantaneously, but with great rapidity. In Europe earthquakes are felt in their greatest force along a line passing through Greece and the south of Italy, Spain, and Portugal. On each side of this line are parallel bands, where the shocks are less intense. In the north of Italy and to the foot of the Alps they are still more feeble and less frequent, but slight tremors are felt occasionally over the whole of Northern Europe. Those experienced in England are probably derived both from Italian and Icelandic volcanos.

The destructive effects of earthquakes arise from an undulating or rolling motion imparted to the solid ground, which is sometimes repeated several times, and during violent shocks resembles the movements of a swell at sea, communicating to bodies on the surface an oblique or vertical movement, throwing down walls or buildings, and crushing every thing beneath them. These movements are accompanied by subterranean noises of various kinds; the most common of which is a low rumbling sound, like that arising from the rapid passage of a heavy carriage. By this wave-like motion of the solid parts of the earth, its fluid parts are violently agitated, vessels at sea are struck upwards by a heavy blow, the sea retires from the coast, and suddenly returns in great waves, which inundate the land.

Great Earthquake of Lisbon. The most tremendous earthquake of modern times is that by which Lisbon suffered so dreadfully in 1755. A subterranean noise resembling thunder was immediately followed by a shock, which destroyed the greater part of the town, and killed 60,000 persons in about six minutes. The quay, with the crowds who had rushed to it for safety from the falling ruins, and with a number of small vessels moored to it, suddenly subsided, leaving a permanent depth of 100 fathoms on its site, and not a single body or fragment of wreck rose to the surface; vessels at sea experienced a shock as if they had struck on a shoal, and on sounding found deep water; the sea first retired from the coast, and then returned in a wave sixty feet high. At Madeira it rose fifteen feet, the ordinary rise of the tide, then at half ebb, being seven feet. At Tangier, on the northern coast of Africa, it rose and fell eighteen times, and less violent movements were occasioned on the coasts of Great Britain and Ireland. The greatest intensity of the shock was in the south of Portugal and Spain, and on the north of Africa, but its effects were felt more or less over the greater part of Europe and the West Indies; and from the intervals which elapsed between the time of its occurrence at Lisbon, and at different other places on the same day, the rate at which the undulating movement travelled appears to have been twenty miles in a minute.

Changes of Level caused by Earthquakes. The fissures which open in the ground during its undulating movements, sometimes discharge jets of water and mud, produced by the derangement of the subterranean drainage. They generally close again immediately, engulphing trees, houses, cattle, and men. They sometimes remain permanently open, and various other surface-changes take place from the production of faults and landslips, the derangement of river courses, and the formation of lakes. The best recorded permanent changes of this kind, because examined by scientific observers, are those which were effected during the successive earthquakes by which Calabria was ravaged, from the beginning of 1783 to the end of 1786. Mr. Lyell, who contends that the forces now acting on the earth furnish not only the type, but the measure of intensity of those which have modified its surface at all former periods, and who ascribes the elevation of the highest mountains to the repetition of earthquakes, at distant intervals, raising the surface a few feet at a time, has given, in his *Principles of Geology*, a very interesting summary of the changes produced by this Calabrian earthquake, as well as by others which have occurred in different parts of the world during the last century. The result is, that earthquakes produce local displacements both of elevation and depression, and that, on the whole, subsidence appears to be the most prevalent. The land subsided at Jamaica in 1692; Lisbon, 1755; Messina, 1783; and Caraccas, 1812. Cutch affords an example of elevation in one part, and of depression in another.

Elevation of the Coast of Chili. The greatest surface elevated was on the coast of Chili, by the earthquake of 1822, when a tract about 100 miles in length, and of unknown breadth, was raised about three feet. Rocks on the beach, with adhering balani, and banks of shells previously covered with shallow water, were laid dry, and proofs of former similar elevations are afforded by a number of parallel terraces, containing marine shells, which occur at various heights extending to fifty feet. These facts, first announced by Mrs. Graham, after being much controverted, are confirmed by the more recent observations of Mr. Darwin and Captain Fitzroy. The latter of these observers has ascertained that, during a subsequent earthquake in 1835, the same coast was raised five feet, and subsequently subsided half that amount. Mr. Darwin has not only corroborated the accounts of elevation during the earthquake of 1822, but has discovered additional proofs of prior upheavements in beds of recent shells, extending to 230 feet above the actual level of the sea; and he has rendered it probable that, besides these sudden elevations at intervals, the coast of Chili is subject to an insensible rise, because the eastern side of South America, from Rio Plata to the Straits of Magellan, presents terraces containing recent shells, though in the provinces near the mouth of the Plata earthquakes are never experienced; and hence he concludes that earthquakes, volcanos, and sudden elevations of land, are but irregularities of action in some more widely extended phenomenon.

In describing the earthquake of 1835, he illustrates the vast surface over which its effects were simultaneously felt, by comparing it with a European area of equal extent, and supposing the shock to have a north and south direction from the North Sea to the Mediterranean, the eastern shores of England to be permanently raised, a train of volcanos to become active in the southern extremity of Norway, a submarine volcano to break out near the northern extremity of Ireland, and the long dormant cones of Central France to send up columns of smoke.*

The neighbourhood of Naples, near Puzzuoli, affords, as we have before shown, proofs of alternate depression and elevation between the third and sixteenth centuries.

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* Proceedings of the Geological Society, vol. ii. pp. 446, 656.

Extinct Volcanos of the Eifel and Auvergne.

The difficulty of defining the limits between active and extinct volcanos has already been adverted to. The same alternation of energy and repose may prevail between different systems of volcanos which is seen between the different vents of the same active group, and we know that eruptions have broken out from cones which have been quiescent for centuries. Under these limitations we may apply the term *extinct* to hills of scoriæ, and ashes of so fresh an aspect that we might suppose them to have been thrown up but yesterday, did we not know that the districts in which they are found have been exempt from the ravages of volcanic action from the remotest periods of history. The principal areas of these extinct craters in Europe are the Eifel, and both banks of the Rhine near Aldernach, also near Heidelburg and Freyberg, Central France, Hungary, Transylvania, Catalonia, &c.

The volcanos of the Eifel have ejected but little lava, and yet are remarkable for the magnitude of the gaseous explosions, which have carried away the summits of hills composed of stratified rocks, mixing up their half-fused fragments with ejected scoriæ and ashes, and forming craters which are now the site of deep lakes. Notwithstanding the immense volume of gaseous matter which we must suppose to have been evolved, and to which the formations of ehrebungs cratere is ascribed, the craters of the Eifel exhibit no traces of intumescence or quâquâversal dip.

The earlier and principal volcanic accumulations of this district are associated with tertiary gravel and brown coal, or lignite, the age of which has not yet been determined in consequence of the rarity of shells. It abounds with the remains of fishes and frogs, all of extinct species. The newer portion is intimately associated with that loamy deposit, known by the name of Loess, an unstratified mass of doubtful origin abounding in land shells of the same species as those now floated down by the Rhine. It occurs in detached patches in the valley, from Basle to Cologne, and on the flanks of the hills which border it. It also extends far up the valleys of the Neckar and the Mayne, and to the neighbourhood of Limburg in Nassau. Though following the line of the Rhine and its tributaries, it does not appear connected with the present drainage.

Mammiferous Remains beneath Lava Currents. The volcanos of Auvergne, Velay, and Cantal, were slightly noticed in our description of the eocene lacustrine strata of those districts. In the Cantal and Velay, no volcanic ejectments or pebbles of lava are found in the lacustrine strata. In Auvergne, a slight intermixture in the upper part of the series proves that the igneous outbursts had commenced during the latter part of the eocene period. We have no evidence when they ceased. The greater part of the eruptions appear to have taken place during the miocene and pliocene eras, judging from the remains of land animals contained in beds of gravel covered by volcanic rocks. Portions of the surface as it existed at successive periods have thus been preserved, and evince the changes which it has undergone by erosion and elevation, and the length of time which must have elapsed during the formation of the igneous products. The remains of lava currents are found at various heights, covering gravel which must have accumulated on the lowest parts of the existing surface, consequently the highest of these beds of gravel must be the oldest. There is occasionally a difference between the levels of the several platforms, amounting to 700 feet. The animal remains found in the gravel beneath the lavas and tufaceous breccias of this district, belong to about forty extinct species of mammalia, some of which are peculiar to it; some are associated with marine shells of the miocene era in other localities, but are not of themselves characteristic of that era, being also found in the ossiferous caverns, and in those pliocene deposits which immediately preceded the erratic block period. The species identified are mastodon minor, and mastodon arvernensis, hippopotamus major, rhinoceros leptorhinus, tapir arvernensis, and hyæna spelæus. Besides these, there are several undetermined species of the following genera: boar, horse, hog, hyæna, felis, bear, deer, canis, otter, beaver, hare, and water-rat. No remains have yet been found beneath the newer lavas, which either occupy the channels of existing rivers, or are very slightly elevated above them.

The volcanos of Central France are ranged in a line, having a general direction from north to south. Those of Hungary constitute insulated groups, which rise abruptly from plains of tertiary strata, in the same manner that the volcanos of the Greek Archipelago and of the Lipari Isles rise from the present bed of the Mediterranean.

Division of Extinct Volcanos into Antediluvian and Postdiluvian.

Of the extinct volcanos which are found in different parts of Europe, some exhibit signs of aqueous denudation, while others, though composed of loose scoriæ and sand, which could not have resisted the action of a violent flood, are in as perfect a state as the cones of Etna and Vesuvius. Hence has arisen the classification into antediluvian and postdiluvian volcanos, adopted by some writers: a classification, the propriety of which has been denied by others, who contend that between the two extremes there exists every intermediate gradation. If volcanic cones have not been denuded by the passage of great waves over the land, to what agency is the removal of their loose materials to be ascribed? In the districts where they occur, they occupy in general the highest parts above the reach of ordinary floods. We are told that atmospheric action has little effect on them; that they retain the integrity of their forms not in spite of their loose and porous nature, but by means of it; that the rain is absorbed as it falls without collecting into rills; and that nothing but a waterspout bursting directly upon them can effect their destruction, so long as they are not rent or engulphed by earthquakes.

We have elsewhere detailed the evidence in favour of the passage of extraordinary marine currents over the British Isles towards the close of the tertiary era, and if a rigorous and impartial review, which the diluvial phenomena of the continent appear yet to require, shall extend the erratic block period to the rest of Europe, those volcanic cones which are uninjured by aqueous denudation must be considered of subsequent formation, and may be called postdiluvian, though the period in question may be wholly unconnected with the Mosaic deluge, or may even have been antecedent to the creation of the human race. From the freshness of their aspect most of the volcanos of Auvergne would be classed as postdiluvian; and it appears certain that their fires have not been in a state of activity for nineteen centuries, for Cæsar is silent respecting volcanic eruptions in Gaul, though he encamped in the neighbourhood of Auvergne, and besieged its principal city; and the situation of Roman baths and bridges, with respect to river channels excavated in some of the most modern lavas, leads to the same conclusion.

Formation of Plutonic or Hypogene Rocks.

For an enumeration of the different varieties of lava, and other volcanic rocks, the reader is referred to the tenth chapter. We must not suppose, however, that the number of igneous products is limited to those which are poured out on the surface. Different modifications of the same elements probably take place in those parts of the melted mass which are never discharged from the interior, but cool with extreme slowness under the influence of great pressure, either from a deep column of lava or of superincumbent strata. We may expect that when rocks, formed thus deep in the earth, are brought by subterranean movements to the surface, they will exhibit a more crystalline character than those portions of the same mass which were poured forth under the atmosphere, or even beneath the pressure of the sea, and thus the same proportions of silica, alumina, lime, magnesia, potassa, and iron, which are the principal ingredients both of volcanic and granitoid rocks, may simultaneously form vitreous, scoriaceous, and compact lava, or granite and greenstone, according to the difference in the pressure and rate of cooling under which their combination was effected.

Those igneous rocks which appear not to have flowed as subaerial or subaqueous lavas, but to have solidified in the interior of the earth, have been called plutonic or hypogene rocks. The structure of igneous rocks, as also that of the aqueous strata in contact with them, may have undergone further modification after their solidification, by the long-continued permeation of water or gases at a high temperature, and by the action of electric currents; and there can be no doubt that porous lava has thus been converted into amygdaloid by the infiltration of carbonate of lime, calcedony, zeolite, stilbite, &c., into its cavities.

CHAPTER XXIII.

TEMPERATURE OF THE INTERIOR OF THE EARTH.—PRESENT STATE OF GEOLOGICAL THEORY.

Gaseous exhalations and thermal springs—geysers of Iceland—connexion of hot springs with regions of extinct volcanos, and lines of dislocation. Internal temperature of the earth—heat of mines and artesian wells.—Primary cause of volcanic action and earthquakes unknown—chemical hypothesis of Sir H. Davy—hypothesis of central heat—theory of Elie de Beaumont respecting the parallelism of contemporaneous chains of mountains—hypothesis of the expansion of gases in a liquid state as a cause of volcanic action—variations of internal temperature from the local accumulation of sedimentary deposits—metallic veins—their dependence on the proximity of igneous rocks—hypothesis of secular refrigeration proposed by Leibnitz.—Prospects of a mathematical basis for physical geology—recapitulation of the principal facts and admitted inferences of geology—igneous and aqueous rocks—our present continents once the bed of the sea—succession of organic forms—lapse of time—elevation of land at successive epochs—change of climate, its cause unknown—gradual passage from the ancient to the present state of the earth—recent origin of man.

Gaseous Exhalations and Thermal Springs.

Besides their solid mineral products, volcanos yield various gaseous exhalations, chlorine, sulphuretted hydrogen, sulphuric acid, nitrogen, and various mineral sublimations, as the chlorides of sodium, potassium, iron, and cobalt, the sulphates of soda and potassa, oxide of copper, sulphur, and sal-ammoniac.

Aqueous vapour, or steam, is among the most abundant of volcanic aeriform products, issuing from crevices, called by the Italians "stufas."

Volcanic regions likewise abound with thermal and mineral springs, charged with carbonic acid, carbonate of lime, and silica. Calcareous springs are the most abundant; the carbonate of lime precipitated by them forms considerable masses of a peculiar limestone, called travertin, and imparts a crystalline and concretionary character to the sedimentary deposits with which it mingles.

Geysers of Iceland. A high temperature appears necessary for the solution of silica. The most celebrated siliceous waters are those of the Azores, and the geysers or boiling springs of Iceland. These latter rise through a thick mass of lava, in the southwest of the island, and are distant about thirty miles from Mount Hecla. They have an intermittent action, playing for a short time, during which they throw up jets of boiling water and steam, with irregular intervals of repose. The largest of them discharges the water by a pipe, or fissure, from eight to ten feet in diameter, which gradually widens near its summit into a basin about sixty yards in circumference, at the top of a mount composed of the siliceous deposits from its spray. While the water is rising in the pipe, and whilst it is thrown out in jets, subterranean noises are heard, like the distant reports of artillery, accompanied by a slight tremor of the ground. The sounds and tremulous motion become more violent, till at last a column of water and vapour is thrown up with loud explosions, in a succession of jets of various heights, but which sometimes exceed 100 feet. When the jet has continued in activity a short time, the pipe is emptied, and the eruption is terminated by a violent rush of steam, with a deafening roar. Stones thrown into the pipes are ejected with great force, and it has been found that, by filling one of them with stones, an eruption could be produced in a few minutes, during which the water was thrown out with greater violence than usual, but a longer interval succeeded before the next ordinary eruption.

The intermittent action of these springs appears to be best explained by supposing the duct of the geyser to communicate with a cavity, the lower part of which is filled with water derived by percolation from above, while steam at a high temperature, such as issues from the vents of volcanic regions, rises from below. The water is thus raised to the boiling point, while the upper part of the cavity is filled with steam under high pressure, the expansive force of which causes the water first to rise in the pipe and overflow the basin, and finally forces it up in jets. When the pressure of the water is removed, the steam itself escapes with great violence; an interval of repose ensues, during which the cavity is again charged with water and steam.

An analysis of the water of the geyser, by Dr. Black, gave the following as the proportions of the mineral substances contained in a gallon:

Soda	5·56	Muriate of Soda	14·42
Alumina	2·80	Sulphate of Soda	8·57
Silica	31·50		

It is probable that the solution of the silica was facilitated by its combination with soda in the rocks from which it was derived.

Connexion of Hot Springs with Extinct Volcanos and Lines of Dislocation.

Thermal springs and gaseous exhalations are not confined to the vicinity of active volcanos; they abound in regions whose fires have been dormant during as long a period as those of Auvergne; we may even extend the generalization with Dr. Daubeny, and say, that they are found wherever lines of dislocation have opened a communication with the interior of the earth, although no volcanic phenomena may be visible at the surface. In our own country the hot springs of Matlock and Bath afford instances of this. They abound in the Alps, Pyrenees, at the base of the Ozark Mountains in North America, and in the range of the Himalayas, as well as many other lines of disturbed country, which are not the seat of volcanic action. The following are the temperature of some of the principal hot springs of Europe:

Great Geyser	209°	Aix les Baines Savoy,	112°
Carlsbad	163	two springs	117
Aix la Chapelle	143	Bath	116
Pyrenees Bagnères	138	Buxton	82
" Barège	120	Bristol	74
		Matlock	68

Internal Temperature of the Earth.

It appears, then, that at a certain depth there is a permanent and nearly inexhaustible source of heat; and the same conclusion is arrived at from mathematical investigations and experiments respecting the thermal state of the interior. Fourier has demonstrated from calculations on the passage of caloric through conducting bodies, that the present surface temperature is compatible with any extreme of heat or cold at a certain depth beneath it. The temperature of the surface of the earth depends principally upon the influence of the sun, modified by various other causes, such as elevation above the mean level of the sea, distribution of land and water, and nature of the surface; but solar influence being the principal source of heat, the mean temperature decreases from the equator towards the poles, nearly in the proportion of the cosine of the latitudes. At a certain depth, which is not always the same, but nowhere exceeds 100 feet, the variations of solar heat are unfelt, and a constant temperature prevails, which is about the same as that of the mean temperature of the surface. Below this point, it appears, from experiments made on the temperature of deep mines, and on the waters of Artesian wells, that as we descend, the water, rocks, and air, grow continually warmer, to the comparatively small depths which have been reached by man. The rate of increase is not uniform, and it varies with the nature of the rock; experiments on the temperature of mines are likewise liable to many sources of error, arising from the heat generated by lights, respiration of workmen, firing of gunpowder, compression of the air, chemical action, &c.; but after allowing for these, Cordier has estimated the mean rate of increase at 1° of Fahrenheit for every fifteen yards of depth; and the same rate of increase has been deduced by Arago from the temperature of the water of Artesian wells at different depths. If the same ratio prevails at greater depths, this frightfully increasing ratio, as it has been called by Sir John Herschel, the boiling point of water will be situated at about two miles; and the melting-point of iron, a heat sufficient to fuse all known rocks, at the depth of twenty-five miles, estimating it, with Professor Daniel, at 2786° Fahrenheit. If we take the melting-point of iron from Wedgwood's pyrometer, which however is proved to give inaccurate results, it will fall within 200 miles from the surface.

Primary Cause of Volcanic Action and Earthquakes unknown.

The primary cause of volcanos and earthquakes is evidently the same, but of that cause we know nothing, all the attempts which have been made to explain it amounting to little more than mere conjectures. That water has a considerable share in producing these convulsions, we may conclude from the quantity of aqueous vapours evolved, and from the general fact of the proximity of volcanos to the sea. The exceptional case of the Mexican volcanos, forty leagues distant from it, may be explained by supposing that they communicate with the vents at the other extremities of the line, nearer the Pacific and Atlantic Oceans. The volcanos of Central Tartary are said to be situated in the neighbourhood of large salt lakes. The chlorine and other saline products evolved during eruptions are such as would result from the decomposition of sea water.

Chemical Hypothesis of Davy. There are two principal hypotheses respecting the cause of volcanic action, one attributing eruptions and earthquakes to a heated nucleus, mechanically disturbed by access of water; the other, endeavouring to explain the phenomena by the decomposition of water by means of alkaline metals existing in the interior in an uncombined state. The latter hypothesis, proposed by Sir Humphry Davy soon after he had succeeded in decomposing the alkalis, was subsequently abandoned by him, and at present finds a warm supporter in Dr. Daubeny. It accords well with the chemical products, and the order in which they are produced; while that of a heated nucleus best explains those extensive wave-like movements of the earth, to which volcanic eruptions appear to be subordinate. The coexistence of the two causes is not impossible; for a nucleus in a state of fusion may contain potassium, sodium, silicum, aluminum, iron, and other metals, in a metallic state.

Hypothesis of Central Heat. The hypothesis that the globe is in the course of gradual refrigeration from an original state of fusion, and even yet retains a high internal temperature, originated with Leibnitz, and has been adopted by some of the most eminent philosophers of modern times; it accords with the astronomical speculations of Sir W. Herschel and Laplace, respecting the condensation of the solar system from a state of gaseous expansion; it has been adopted by Cordier as an explanation of volcanic phenomena; and Fourier has declared in favour of its probability from mathematical calculations, and the rate at which the internal temperature increases with the depth. Humboldt has even ventured to define volcanic action as the influence exerted by the interior of a planet on its external covering, during the different stages of refrigeration; Elie de Beaumont has connected the doctrine of secular refrigeration with his theory of the parallelism of contemporaneous mountain chains.

Theory of Elie de Beaumont respecting Mountain Chains. This theory embraces the following points: 1. That in the history of the earth long periods of comparative repose, during which the deposition of sedimentary matter went on in regular continuity, have been interrupted by short peiods of paroxysmal violence; 2. That during each of these periods of disturbance, a great number of mountain chains have been formed *suddenly;* 3. That all the chains of each paroxysmal period have one uniform direction, being parallel, or nearly parallel, (even when situated in remote regions,) to each other, and to a great circle of the sphere; but those of different periods are parallel to different circles, the poles of these circular systems being very irregularly placed in the globe; 4. Each period of disruption has accorded with a great change in organic types; 5. These paroxysmal disturbances, which have recurred at intervals from the remotest geological periods, may be renewed; and the present state of repose may be broken by the sudden elevation of other parallel chains of mountains; 6. It is probable that one of these convulsions has occurred within the historic era, when the Andes were upheaved to their present height; that chain appearing to be the last elevated, for it is the best defined and least obliterated feature on the present surface of the globe; 7. The instantaneous upheaving of great mountain chains from the ocean must cause a violent agitation of the waters; and the rise of the Andes may perhaps have produced the transient deluge which is noticed among the traditions of all nations; and Lastly, These successive revolutions are not the results of ordinary volcanic action, but may depend on the secular refrigeration of the heated interior of our planet.

M. de Beaumont points out twelve different systems of disturbance in Europe, defined by the direction of the axes of the chains, and the formations which have been affected by the disturbing movement. These systems are:*

1. *That of Westmoreland and the Hundstruck.* It comprises the mountains of Westmoreland, having a strike about N. E. by E., of the Eifel, Nassau, the Hundstruck, and the central part of the Vosges N. E. The disturbed rocks are those of the Cambrian and Silurian systems; and the carboniferous system rests on their upturned edges, or has been deposited at the feet of the mountains composed of them.

2. *System of the Ballons (Vosges), and of the Hills of the Boccage (Calvados).* This system exhibits some indications of a disturbance prior to the last; rocks of the Silurian type being unconformable to those of the Cambrian.

3. *System of the North of England.* The great Penine dislocation, Craven and Derbyshire faults and Ribblesdale anticlinals. The coal measures are disturbed, the poikilitic sandstone horizontal.

4. *System of the Netherlands and South Wales.* The great range of the carboniferous rocks from the vicinity of Aix la Chapelle to St. Bride's Bay exhibits, where not concealed by other rocks, a direction from E. to W. for 400 miles. The beds of the new red sandstone reposing on this formation, are considered not to be so ancient as those of the preceding system.

5. *System of the Rhine.* The Vosges and Swarzwald, which terminate opposite each other, in two long cliffs parallel to one another and to the course of the Rhine, are apparently due to great faults, having a direction S. 15° W., and N. 15° E., preceding the deposit of the grès bigarré, muschelkalk, and variegated marls, in the basin of Alsace.

6. *System of the Southwest coast of Britanny and La Vendée, of Morvan, of the Bohemerwald, and of the Thuringerwald.* The general direction is from N.W. to S.E., and the variegated marls, muschelkalk, and older rocks are disturbed; the oolitic series, including the lias, undisturbed.

7. *System of the Pilas Cote d'Or and the Erzgebirge*, containing also a considerable portion of the Cevennes. The oolitic rocks are disturbed, and the cretaceous series (greensand and chalk) retain apparently their original position. The general direction is N.E. and S.W.

8. *System of Mount Viso.* The French Alps and the southwest extremity of the Jura present a series of crests and dislocations, with a direction N.N.W., in which the greensand and the chalk are upheaved as well as the oolitic series. The eastern crests of the Devolny, on the north of Gap, are formed of the oldest beds of the

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* See De La Beche's Manual of Geology.

greensand and chalk, thrown up in the above direction, and raised more than 4700 English feet above the sea; while at the base of these escarpments, and at a lower elevation by about 2000 feet, those upper beds of the cretaceous system, which contain nummulites, cerithia, and other tertiary genera, are deposited horizontally.

9. *Pyreneo-Apennine System.* General direction, W.N.W. and E.S.E. This system includes the whole chain of the Pyrenees, the northern and some other ridges of the Apennines, those on the N.E. of the Adriatic, those of the Morea, nearly the whole of the Carpathians, and a great series of inequalities, continued from that chain through the N.E. escarpment of the Hartz to Northern Germany. In the Pyrenees the whole cretaceous system is disturbed, the tertiary strata (miocene) are horizontal at their base.

10. *Systems of the Isles of Corsica and Sardinia.* This disturbance took place during the tertiary era. The north and south direction observed in Corsica and Sardinia, is also met with in many small valleys, and ridges of mountains, in the Apennines and Istria.

11. *System of the Western Alps.* Mean direction of the axis about N.N.E. and W.S.W. The disturbance appears to have followed the deposition of tertiary beds of the shelly molasse of the miocene era. These movements were succeeded by great horizontal deposits of old diluvial gravel at the base of the Western Alps.

12. *System of the Eastern Alps from the Valais int Austria, comprising the Chains of the Ventoux, the Lebaron, and the St. Baume, in Provence.* Direction E. $\frac{1}{4}$ N.E., W. $\frac{1}{4}$ S.W. This system and the last do not pass into one another by any flexure of the strata corresponding with the bend of the whole chain, but they meet at an angle marked by a double system of breaks and fissures, one passing in the direction of the eastern, the other of the western parts of the chain.

In the Eastern Alps, the old diluvial gravel, which in the last system was horizontal, has undergone disturbance, and the newer diluvium, including the erratic blocks, rolled off the higher Alps during this last period of elevation.

That different parts of the same continent have been elevated at different successive epochs does not admit of a doubt, from the evidence of horizontal strata reposing on others which are in-inclined and contorted, and it appears that there is some relation between the strike of the beds and the period of elevation, but what that relation is it will require a long series of observations to determine, and to ascertain what is the rule and what the exception. The parallelism of all the dislocations of the same epoch cannot be considered as proved, though some accordance prevails between those of a particular age within limited regions, and some cases of it have been observed between others which are remote.

Facts have been observed which are favourable, and others which are unfavourable, to M. De Beaumont's theory, and the British Islands afford instances of both. The strongest facts in favour of it are the N. E. and S. W. axes of the slate regions of Wales, Cumberland, Devon, the Grampians, Lammermuirs, Donegal, and Cavan. On the other hand, the system of the north of England comprises the Ribblesdale anticlinals, having also a N. E. and S. W. direction, the Penine fault ranging N. N. E. and S. S. W., and the Cavan fault whose range is W. S. W. We have again east and west lines of disturbance, at such distant epochs as those when the coal measures of South Wales, and the tertiaries of the Isle of Wight were elevated.

We have already noticed two kinds of elevation in England, one by which the strata have been fractured and thrown into highly inclined positions, the other by which they have been raised like the plains of the poikilitic sandstone to a considerable elevation above the sea, with very slight disturbance of their orginal horizontality, and the position and range of the more recent strata appear to indicate a continued elevatory action along a line ranging nearly N. E. and S. W., by which the area of the sea to the eastward of it has been gradually reduced within narrower limits. M. De Beaumont himself, admits cases of parallelism between the disturbances of different eras, remarking that the systems 7, 9, and 10, are respectively parallel to the systems 1, 2, 3, the corresponding directions having succeeded one another in the same order, thus leading to the supposition that there has been a kind of periodical recurrence of elevation along the same, or nearly the same lines.

There is, likewise, great difficulty in determining elevations of the same period to have been strictly contemporaneous, our only measures of geological time being the periods during which certain groups of animals flourished, and these periods are so indefinite that we cannot be certain whether thousands of years may not have elapsed between different dislocations which have fractured strata containing the same organic remains. The series of deposits at present known is, moreover, of so broken and imperfect a nature as to lead to the suspicion that between some of the groups now classed as consecutive, a long interval of time may have elapsed, of which, as our knowledge of the earth's structure extends, some distant region may hereafter furnish the records. These difficulties beset us in our endeavours to form more than a loose approximation to a chronological arrangement of the elevation of even contiguous chains of mountains, and when we extend our investigations to distant parts of the earth, they are increased by our present ignorance of the lines of contemporaneous stratification, or the equivalents of the European deposits.

The weakest part of M. De Beaumont's generalization is that which connects each period of elevation with a great change of organic forms. Two great breaks occur as we have seen in the continuity of sedimentary deposits in England, the one between the Cambrian and carboniferous systems, the other between the carboniferous system and the magnesian limestone, and yet it is not until after the latter deposits that any great change takes place in the general character of the fossils. The skirts of the Eastern Alps also contain fossils, conforming both to the secondary and tertiary types.

Hypothesis of the Expansion of Liquid Gases as a cause of Volcanic Action. Mr. Lyell, who considers a central nucleus of heated fluid as incompatible with the ordinary repose of the surface, has recourse for the cause of volcanic phenomena to chemical changes produced in a solid interior, by electric currents, and to the sudden return into the aeriform state of gases converted by pressure into fluids, since it has been ascertained by the experiments of Mr. Faraday, and others, that at temperatures from 30° to 50° Fahr., the gases which are most copiously disengaged from volcanos may be reduced to the liquid form, by a pressure varying from fifteen to fifty atmospheres, which is much less than that of a column of lava extending from the level of the sea to the summit of Vesuvius.

Variations of Internal Temperature from Accumulation of Sedimentary Deposits. Sir John Herschel, who has lately offered some suggestions on the cause of volcanic action, observes, that it has always been his greatest difficulty in geology to find a *primum mobile* for the volcano taken as a general, and not a local phenomenon, considering the different theories insufficient, wanting in explicitness, and not going high enough in the inquiry, or up to its true beginning, and also as giving, in some respects, a wrong notion of the process itself.

How, he asks, came the gases which are evolved to be condensed? Why did they submit to be urged to liquefaction? If they were not originally elastic, but became so by subterranean heat, whence came the heat, and why did it come? How came the pressure to be removed, and what caused the crack? It seems clear that if the gaseous or aqueous vapour were once free at so high a degree of elasticity as is presumed, there exists no adequate cause for their confinement; we are forced therefore to admit that the elastic force has been superadded, during their sojourn below, by an accession of temperature. Agreeing with Mr. Lyell, that the ordinary repose of the surface argues a wonderful inertness in the interior, where he considers every thing is motionless, and debarred from the invasion of a circulating current, or casual injection of intensely hot liquid from below, he suggests as a consequence, resulting by known regular and calculable laws, from assumed high central temperature, that the accumulation of thick and extensive sedimentary deposits at the bottom of deep seas may produce volcanic phenomena, by causing subterranean oscillations of the isothermal surfaces of great temperature.

The effects of the transfer of the materials of continents from above to below the depths of the sea, will be twofold, he says, a mechanical subversion of the equilibrium of pressure, and, by a different process, a subversion of the equilibrium of temperature, by increasing the coating and removing the cooling effects of the surface, and thus bringing a high temperature to a point where it did not exist before. This will be an exceedingly slow process, and it will depend, 1st, on the depth of matter deposited, 2d, on the quantity of water retained by it under the great pressure, 3d, on the tenacity of the incumbent mass, whether the influx of caloric from below, *which must take place*, acting on the water, shall either heave up the whole mass as a continent, or shall crack it and escape as a submarine volcano, or shall be suppressed until the main weight of the continually accumulating mass breaks the lateral supports, at or near the coast lines, and opens there a chain of volcanos. As the greatest transfer of materials to the bottom of the ocean is produced on the coast line by the action of the sea, while the quantity carried down by rivers from the surface of continents is comparatively trifling, the greatest local accumulation of pressure is in central areas of deep seas, but the greatest local relief takes place along the abraded coast lines. Here, therefore, the chief volcanic vents should occur. Thus, the accumulation of sedimentary deposits, the phenomena of earthquakes, volcanic explosions, &c., may arise, but if all goes on in quiet, the only consequence will be the obliteration of organic remains and lines of stratification and the production of *metamorphic*, or primary stratified rocks.* A theory identical in its leading point had previously been given by Mr. Babbage.

Metallic Veins.

The origin of metallic veins must be considered as connected with internal heat. The assumption prevalent among the practical miners of Cornwall, that all metallic deposits are contemporaneous with the rocks which inclose them, is unequivocally disproved, as remarked at p. 276, by those veins which traverse stratified rocks in the lead districts of the carboniferous limestone. At the same time there are some which we must allow to have separated during the gradual passage of the masses to a solid state; such are the minerals appearing disseminated through rocks in separate particles, and sometimes in small intersecting veins or strings (like those of carbonate of lime or quartz) which are not continuous. These have been termed by Professor Sedgwick *veins of segregation.* Metallic *beds* again must have been contemporaneous with the strata to which they are subordinate; such are the masses of reniform hæmatite alternating with beds of mountain limestone in Cumberland. Lead and copper also sometimes occur in beds, though the appearances are often deceptive, the supposed beds being merely horizontal branches from a vertical vein. The great copper *pipe* veins of Ecton must likewise be considered contemporaneous with the shale which contains them. But the regular metalliferous lodes, or rake veins, the most common form in which metals occur, must have been cracks or fissures produced during periods of elevation, and filled subsequently to the consolidation of the rocks. The mode in which the metallic matter was introduced is, and must long continue, one of the most obscure questions of geology. Of the various hypotheses proposed as solutions of it, none can be considered of universal application. That of Werner, which supposes the contents of veins to have been poured in from above in a state of aqueous solution, is the most untenable. There may be exceptional cases, but in general the metallic matter has proceeded from below—injected in some cases in a state of fusion, as in the *elvans,* or porphyritic dikes—in others, sublimed from a heated mass, and condensed on a cooler surface; but the experiments of Mr. Fox, which show that electric currents, excited perhaps by heat, circulate among metallic veins, leave little doubt that the greater part of them owe their contents accumulated on the walls or sides of the fissure in vertical laminae, to the developement on a grand scale of electro-chemical action. By such operations insulated masses of metallic matter, occurring in sparry nests and cavities, or in the hollow of shells, may have been transferred from the sides of a vein through a considerable mass of solid rock.

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* Letter to Mr. Lyell, Proceedings of Geological Society, vol. ii., pp. 548, 596.

Miners have observed a relation between the productiveness and the direction of veins. The most generally productive are those which range nearly east and west. This rule prevails in nearly all the mining districts of Europe and in Mexico. In every mining district there are several sets of veins, some of which intersect the others, and always interrupt their continuity or displace them. These were considered by Werner as more recent than the veins which they displace. There is likewise some relation, in particular districts, between the direction of veins and the nature of their contents. On these principles he framed a classification of the veins of Saxony, which he considered applicable to those of England. Mr. Carne, on the same principles, has divided the veins of Cornwall into eight classes, of the following relative antiquity:—1, The old tin lodes; 2, the more recent tin lodes; 3, the oldest east and west copper lodes; 4, the contra or quarter-point copper lodes; 5, the cross courses;

6, the more recent copper lodes; 7, the flukans or clay veins; 8, the slides or faults filled with clay: Mr. Hopkins, however, who has investigated the subject of fissures mathematically, denies the soundness of the conclusion that the continuous is more recent than the discontinuous vein; for in the first place, the displacement may be only apparent, and the irregularity of either of the fissures may be original from having deviated along the other, as the line of least resistance, in which case the discontinuous fissure will be the most recent; and secondly, if the displacement be real, the two may be contemporaneous.

Dependence of rich Mineral Districts on the proximity of Igneous Rocks. It is a point of great importance to the miner to determine the general laws which regulate the distribution of metals to different parts of the series, or to ascertain what rocks are most productive of rich deposits of ore. It is generally true that these are most abundant in the older systems; but this is not always the case, and rules which guide the miner to the discovery of new veins in one country fail him when applied to another. From a review of the principal mining districts of Great Britain and Ireland, Norway, France, Germany, Hungary, the Southern Alps, Russia, and the North of the Black Sea, M. Necker has announced the generalization that rich metallic districts are dependent on the proximity of igneous rocks and axes of disturbance, and every subsequent observation has tended to confirm this theory. Several instances have been mentioned, during our description of the stratified rocks, of the production of small nests and strings of various metals in rocks not otherwise metalliferous, in the vicinity of outbursts of trap. On comparing the relative connexion of metallic accumulations with different igneous rocks, M. Necker finds that they are more abundant in granite, certain porphyries, syenites, amygdaloids, and traps, which he calls underlying stratified rocks, than in the newer porphyries, dolorites, and true volcanic rocks, which he terms overlying. It is proximity to these underlying masses that renders the lower stratified rocks in general the most metalliferous, and that causes the killas of Cornwall, (and even the carboniferous strata,) to be richer in metals than rocks of the same age in North Wales. The mining districts of Shelve and Nant y Moen, situated in the upper part of the Cambrian and in the Silurian system, are connected with igneous outbursts; and axes of disturbance have caused abundance of lead veins in the carboniferous limestone of the Mendips, Flintshire, and Derbyshire, and Northumberland, while they are rare in the broad undulations of the same rock which cover so large a surface in Ireland. Mineral veins are scarcely known in England in the upper part of the secondary series, which is there but little disturbed, and unbreached by igneous rocks, but they are profitably worked in the same rocks, on the flanks of some of the continental chains, and in the Andes even the tertiary series becomes metalliferous and crystalline in contact with granite.

This dependence of numerous fissures, filled with rich deposits of ore, on the proximity of granitic and other porphyritic rocks, furnishes a general rule of the highest practical value to the miner, while it forms an important step in our progress towards a knowledge of the causes which have influenced the formation and repletion of metallic veins. "These," to use the words of Professor Whewell, "formed the earliest subjects of geological speculation, and will probably remain as a problem for its later stages, when our insight into the laws of slow chemical changes shall be far greater than it is at present."

Hypothesis of Secular Refrigeration proposed by Leibnitz.

The doctrine of a gradually cooling globe haunts the geologist at every step in his attempts to advance to a knowledge of causes, and appears to offer a probable explanation of many geological phenomena, such as the universal prevalence of granite and the crystalline stratified rocks, the temperature of the earlier climates, as evinced by organic remains, the general diffusion of that high temperature, its apparent independence of solar heat, and gradual decrease in later periods, while the mountain chains by which the surface has successively been ridged, the long periods of ordinary action, separated, apparently, by short intervals of disturbance, and accompanied by clysmical or diluvial irruptions of the sea over the land, may all be attributed to the fracture and collapse of the external crust accommodating itself to the contracting dimensions of the cooling nucleus. To the objection urged against this hypothesis, that a contraction of the dimensions of the globe would cause a diminution of the length of the day, whereas it appears not to have varied by $\frac{1}{300}$th of a second since the time of Hipparchus, it is replied that the process of refrigeration has now become so exceedingly slow as to be imperceptible for periods of no greater duration than two thousand years, and that the crust does not accommodate itself to the altered dimensions of the interior gradually, but remains for a long time in a state of tension between each collapse.

Prospects of a Mathematical Basis for Geology.

But however important inquiries into the state of the interior of the globe must be, in all attempts to advance from laws of phenomena to laws of causation, and however plausible the hypothesis of central fluidity, as a means of explaining some of the dark problems of geology, stronger proofs must be obtained before it will be generally admitted. If we are ever to arrive at certain knowledge on this subject, it can only be by means of refined mathematical and astronomical investigations. In our attempts to penetrate the dark recesses of the earth, we have evoked spirits which can only be laid by the spells of more potent magicians—we have raised questions which are not to be solved by the hammer of the geologist, but they have attracted the attention of the most eminent mathematicians of the age, and a solution of them may possibly be within their reach. We are told by one who is no mean authority in whatever relates to exact science, of the hopes as well as the difficulties which attend the attempt to construct a system of physical geology:

"We have accumulated," says Professor Whewell, addressing the Geological Society, "a vast store of facts of observation, and have laboured with intense curiosity, but hitherto with very imperfect success, to extract from these facts a clear and connected knowledge of the history of the earth's changes. Nearly the same was the condition of astronomy at the time of Kepler, when the accumulated observations of twenty centuries resisted all the attempts of that ingenious man and his contemporaries to construct a science of physical astronomy. But though checked by such failures, they were not far from success; and when, for the next succeeding century, philosophers had employed themselves in creating a distinct science of dynamics, the science of physical astronomy, full and complete, made its appearance, as if it were a matter of course; and thus showed the wisdom of separately cultivating the study of causes, and the classification of facts." "If," he elsewhere observes, "from those proximate causes of change of which I have spoken, we proceed to those ulterior causes by which events such as these were produced—to the subterraneons machinery by which islands and continents appear and vanish in the great drama of the world's physical history—we have before us questions still more obscure, but questions which we must ask and answer, in order to entitle ourselves to look, with any hope, towards geological theory. Of late years, an opinion has taken root among us, that the dynamics of geology must invoke the aid of mathematical reasoning and calculation, as the dynamics of astronomy did at the turning point of its splendid career. Nor can we hesitate to accept this opinion, and to look forward to the mathematical cultivation of physical geology, as one of the destined stages of our progress towards truth. But we must remember, that in order to pursue this path with advantage, we have, in every instance two steps to make, each of which demands great sagacity, and may require much time and labour. These two steps are to *propose* the right problem, and to *solve* it. Last year, an important example of this kind was brought under your notice by my predecessor. The supposition that there are, beneath the crust of the terrestrial globe, liquid or semi-liquid masses which exert a pressure upwards, leads to the inquiry what phenomena of fissure, disruption, and dislocation, this subterraneous strain would produce. The answer to this inquiry must be given by mathematical reasoning, from mechanical principles; and Mr. Hopkins, who proposed, and to a considerable extent solved this problem, has put forth a set of results, with which, so far as they are definite and decisive, it will be highly important to compare the existing phenomena of disturbed districts.

After noticing the speculations of Sir John Herschel and Mr. Babbage, already cited, on the changes of internal temperature, by the partial distribution of sedimentary matter over the bottom of the ocean, describing them as but the enunciation of a problem requiring no small share of mathematical skill for its solution, and observing, that in order to render them of permanent use, it will be necessary to express, in some probable numbers, the laws of the results as affected by the conductibility of the earth's mass, the rate and thickness of the deposit, &c., whether, for instance, if a deposit of one thousand feet thick be, as we know it is, quite insufficient to occasion a metamorphic condition of its lower strata, one of ten or twenty thousand feet would call into play such a process,—he proceeds: "To answer questions like these, of which a vast number must at once occur to our minds, we have many experimental data to collect, and many intricate calculations to follow out. And it would be easy to point out problems of a still more abstruse kind, in which we no less require aid from the mathematician, before we can proceed in our generalizations. May we not hope to see some fortunate man of genius unveil to us the mechanics of crystalline forces? And when that is done, can we doubt that we shall have a ray of new light thrown upon those extraordinary phenomena of slaty cleavage in mountain masses which lately have been brought under our notice? Or, recollecting the experiments of Sir James Hall, (a striking step in geological dynamics,) may we not hope, then, to learn how these crystalline forces are stimulated by heat; and thus follow the metamorphic process into its innermost recesses? These, and a thousand such questions, lie before us; tangled and arduous inquiries, no doubt, but connected by their common bearing upon one great subject:

A mighty maze, but not without a plan.

And through this maze we must force our way, in order to advance to any sound geological theory. The task is one of labour and difficulty; but I well know that you will not shrink from it on that account. Those who aspire to the felicity of knowing the causes of things, must not only trample under foot the fears of a timid unphilosophical spirit, which the poet deems so necessary a preparation, but they must look with a steady eye upon difficulty as well as violence. They must regard the terrors of the volcano and the earthquake, the secret paths by which hot and cold and moist and dry ran into their places, the wildest rush of fluid mass, the latent powers which give solidity to the rock, as operations of which they have to trace the laws, and measure the quantities with mathematical exactness. And though there can be no doubt that the greater part of us will be more usefully employed in endeavouring to add to the stores of descriptive geology, than in these abstruse and intricate investigations, yet we must always receive with great pleasure any communications containing real advances in the mathematical dynamics of geology, from those whose studies and whose powers enable them to lay an effectual grasp on these complex and refractory problems."*

If, in the cultivation of geology by proficients in the science, it is advisable to separate the classification of facts from the study of causes, such separation must be still more advantageous for those who are entering on its elementary details. We have kept this object in view in the present work, though it has not always been possible strictly to adhere to it. It is difficult, for instance, to describe the primary stratified rocks, or the loose covering of the earth, without noticing the discordance of opinion which prevails respecting their origin; neither can we treat of igneous rocks and internal temperature, avoiding at the same time all allusion to the various hypotheses proposed with reference to the causes of volcanic phenomena, and to the theory of secular refrigeration as connected with the elevation of continents and change of climate. The mass of undoubted facts, and the admitted inferences from them, ought, however, to receive the chief attention of the student; questions which are still subjects of inquiry and discussion, being reserved for a more advanced stage of his progress. Let us, therefore, in conclusion, recapitulate those principal facts and limited generalizations which may be deemed established, briefly pointing out those questions respecting laws of causation which are still involved in obscurity.

Summary of admitted Facts and Inferences in Geology.

1. Rocks are now forming, both by the agency of fire and water, and each process has been employed in times past, in the formation of the crust of the earth.

2. The materials of which this crust is composed, are arranged in a determinate order of superposition.

3. Its base consists of crystalline unstratified masses, which have frequently pierced through the superincumbent beds, have produced the same alterations on the sedimentary rocks in contact with them which are produced by igneous rocks, and they pass by insensible gradations of composition into known igneous products.

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* Anniversary Address, Proceedings of Geological Society, vol. ii. p. 648.

The pyrogenous origin of these granitic rocks, once disputed, is now universally admitted. The only difference of opinion is respecting the time when they were in a state of fusion. Some regard them as the first crust that cooled on the surface of a globe, in a state of original incandescence; others consider them as the fused and reconsolidated materials of older sedimentary strata than any now visible. If this opinion be correct, many other series of events, like that indicated by the fossiliferous strata, may have occurred, of which we can never recover the monuments.

When granite sends off veins into the rocks which cover it, there is no doubt that it is the more recent of the two. Tried by this test, we find the granite of the Grampians younger than the mica slate, that of Cumberland and Wicklow than the clay slate, that of Devonshire than the carboniferous system. The continent of Europe furnishes instances of granite more recent than the Silurian, oolitic, and cretaceous systems; and that of the Andes appears to have been in a fluid state during the tertiary era. In short, it is difficult to point out any granite which we can prove to be older than rocks of the Cambrian system,—but, at the same time, the paucity of species found in those early fossiliferous rocks, and their progressive increase, as we ascend in the series, renders it probable that we see the commencement of organic life, and of watery action on the surface of the earth.

4. The granitic rocks are succeeded in the ascending order by crystalline strata, destitute, like them, of organic remains. They exhibit traces of sedimentary deposit, and graduate on the one hand into the slate series of decided aqueous formation, and on the other into granitic rocks, to which, on the above evidence, an igneous origin is assigned. The prevalent opinion respecting them is, that they are sedimentary deposits altered by heat; but the amount of change is still matter of controversy. By some, their peculiar aspect is supposed the result of the degradation and decomposition of the first granitic crust; and the absence of fossils arises from the peculiar condition (perhaps the heat) of the early ocean, which rendered it unfit for the abode of organic life.

According to the other view, the fossiliferous strata are approaching a state of fusion, the last stage of which is granite; fossils which they once contained have disappeared during the process, and any sedimentary rocks may be reduced to the same state.

5. *Our present Continents once the Bed of the Sea.* These nonfossiliferous strata are succeeded by a vast series of stratified rocks, similar to those aqueous deposits now observed to be forming at the mouths of rivers, and in shallow seas. Like them, they abound with the shells and corals which must have lived on or near the spots where they are found, and contain plants and other terrestrial remains swept down from the land.

This series is several miles thick. The lower strata must be the oldest, the uppermost the most recent. Each must have formed in succession the bed of the sea; and exhibits the organic forms which lived during its deposition.

6. *Succession of Organic Forms.* This series is divisible into several groups, each distinguished, over very extensive areas, by peculiar groups of organic remains. The ancient races of plants and animals thus preserved for our observation, exhibit a close analogy to existing races, are susceptible of arrangement into the same leading divisions, founded on important points of structure, yet are distinguished from them by considerable differences of detail. These differences consist, in general, of minute specific distinctions, but some of the fossils are not referrible to existing genera, or even families. The greatest contrast prevails between those groups of organic remains which are derived from the extremes of the series, the greatest resemblance between those which are nearest to one another in the order of succession. The passage from one assemblage of fossils to another, is for the most part, gradual. These results are founded chiefly on observations made in Europe, but they are more than local truths, for groups of fossils which characterize a certain system of strata in one country, are found in the same part of the series in countries separated by thousands of miles. The assemblages of contemporaneous fossils exhibit a general similarity of aspect at such distant points, accompanied by some local peculiarities, which increase in proportion to the distance. Local diversities likewise are more prevalent in the upper than in the lower part of the series.

7. *Lapse of Time.* An immense lapse of time must have been consumed in the formation of the stratified rocks. In the existing system of nature, time would be required for the formation of a bed of sandstone bearing an insignificant proportion to the sum of the series. Time would be requisite for the production of its fragmentary materials from the wear of older rocks, for their arrangement into the numerous layers of which it is composed, for the growth of the organic remains which it contains. Far longer then must have been the period indicated by the more complicated details of a single formation, its alternations of sandstones with clays and limestones, of lava currents with aqueous deposits, of strata inclosing trees, the growth of centuries, swept down by inundations from the land, with others containing marine molluscs in every stage of growth, all implying periodical cessations and renewals of mechanical, chemical, and vital action. When we trace numerous repetitions of these alternations through formation after formation, and system after system, constituting a succession of strata some miles in thickness; when we see that rocks formed by this slow process have been consolidated and broken up, their fragments, containing fossil remains, reconsolidated into conglomerate rocks, those conglome-

rates again broken up and again consolidated; and, lastly, when we contemplate the gradual change of organic types from the oldest to the most recent strata, every candid inquirer must admit that the few thousand years during which the human race has been placed upon the earth sink into insignificance, compared with the time required for this succession of events.

8. *Elevation of Land.* The greater part of the dry land whose structure has yet been examined, that is, Europe, North America, India, and a small part of Africa, is composed either of these fossiliferous strata, or of igneous rocks which can be proved to have burst through them; and as all aqueous deposits must have been originally nearly horizontal, and portions of them are now found on the flanks of mountains broken, contorted, and elevated into positions making considerable angles with the horizon, the desiccation of part of the ancient bed of the sea appears to have been effected by subterranean forces acting along certain lines, which have brought up with them, sometimes in a fluid, sometimes in a solid state, the igneous rocks which form the central axis of most chains of mountains.

9. *At successive Epochs.* These elevations have taken place at successive epochs, and the relative age of different mountain chains is determined by observing what strata have been disturbed and what lie upon or unconformably against them.

10. Fossiliferous strata are often found raised to great heights above the sea, with very slight disturbance of their horizontality. These constitute, perhaps, nearly half the area of the dry land, and their desiccation appears to have been effected by a gradual expansion beneath an extensive region, or by the repetition of a number of minor shocks. We have examples of both these kinds of movements now in action.

11. From the fractured and contorted state of stratified rocks in the vicinity of mountains, they appear to have been thrown up by sudden and violent convulsions. Disturbances of this magnitude have not happened within the range of human experience, and therefore their occurrence in periods antecedent to the existence of the human race is denied by some geologists.

12. *Internal Heat.* The elevation of mountains and continents, the phenomena of volcanos and earthquakes, appear to be different modifications of subterranean forces depending on the thermal state of the interior, the nature of which must be left to the researches of mathematicians and astronomers. It is certain that the temperature of the earth increases progressively to small depths, and that, if the same progression continues to greater depths, all known substances must be in a state of fusion a few miles below the surface.

13. *Change of Climate.* The tropical aspect of the vegetation of the lower part of the fossiliferous series and its lamelliferous corals, the large chambered shells, corals, and saurians of the middle part, the palms, monkeys and boas, with the nautili, and

other shells of the tertiary deposits, indicate that a high but gradually decreasing temperature prevailed in northern latitudes during the earlier geological epohcs; and this high temperature appears to have been generally diffused over the globe, plants of nearly the same species being found in the carboniferous strata of Europe, Canada, Greenland, and Australia, which, from their high state of preservation, could not have grown far from the localities where they occur.

14. *Cause of the Change of Climate unknown.* We have made as little progress towards a knowledge of the cause of this change of climate as towards a discovery of the primary source of subterranean movements. We have already noticed the hypothesis of a gradually cooling globe—that of a change of axis is precluded by its inconsistency with the figure of the earth and the laws of equilibrium. In a recent inquiry into the astronomical causes which may have influenced geological changes, Sir John Herschel puts the secular variation of the obliquity of the ecliptic out of the question, as confined within limits too narrow to have caused any sensible effect on our climates, but shows by direct calculations that the mean annual amount of solar heat received by the earth is inversely proportional to the minor axis of the ellipse it describes at different periods: that is, it diminishes or increases with the diminution or increase of eccentricity. The eccentricity of the earth's orbit is slowly decreasing. The calculations necessary to determine whether limits of variation are such that any sensible change of temperature can have been produced by this cause, though practicable, are very laborious, and have never yet been made; but assuming hypothetically that the eccentricity may once have been as great as that actually existing in the orbits of some of the planets, he proves that its slow diminution *may* have produced a change of climate to as great an extent as geological indications appear to require.

On this hypothesis, other modifications in the diffusion of light and heat would be caused by the precession of the equinoxes and the place of apogee. By the continual movement of these points they will make the entire circuit of our orbit after the completion of a long cycle, so that during one part of it our summers would coincide with the greatest, and during another with the least, distance from the sun; and, in an orbit of considerable eccentricity, the conditions would produce at one time a climate approaching to perpetual spring, and at another to the extreme vicissitudes of a burning summer and a rigorous winter, and that during periods sufficiently long to impress a corresponding character on the vegetable and perhaps animal productions of both.

In the existing economy of nature considerable differences of climate are produced in corresponding latitudes by differences in the distribution of land and water, and Mr. Lyell has proposed this cause as alone sufficient to have produced the high temperature of the early geological epochs, by the preponderance of land in equatorial latitudes and of ocean towards the poles.

15. *Gradual Change from the ancient to the present State of the Earth.* The change from one condition of the terraqueous surface to another, as indicated by different groups of organic bodies, has been gradual. The greatest break observable in Europe is between the cretaceous and the tertiary series, but slight local indications of a passage from one to the other have been discovered within that area, and may hereafter be found more completely developed in other parts of the world.

16. Of all the geological epochs, the tertiary exhibits the closest analogy to that in which we live. Its organic remains are more diversified than in the secondary rocks; mammalia, which, with one exceptional case, are not found in older strata in any part of the world, then became abundant, extinct genera first making their appearance, then extinct species of living genera. Existing species of molluscs were gradually introduced, as well as a new group of plants distinct from the three which preceded it, and approximating more closely to living species.

17. The passage from the tertiary to the modern period was gradual. Groups of molluscs, identical with those now living in the adjoining waters, were coexistent in the same regions with extinct species of mammalia.

18. While these extinct species of mammalia inhabited England, and its seas contained the same groups of molluscs that are now found in them, marine currents of extraordinary violence dispersed large boulders from the North over the British Islands. These are by some geologists treated as deposits formed by the ordinary action of the sea, and classed as raised beaches. This assumption is controverted in the nineteenth chapter, and proofs adduced of the transient action of the sea upon land inhabited by large terrestrial mammalia. With these diluvial currents, elephants, hyænas, &c., disappeared from England, and they are succeeded by strata containing the remains of man and of the animals now inhabiting the country.

19. A great dispersion of boulders appears to have taken place over various parts of Europe and North America about the same period. In the vicinity of the Alps, there are two distinct diluvial accumulations connected with different elevations of that chain.

20. *Recent Origin of Man.* We have, at present, no evidence whether the most recent diluvial action occurred after the creation of man. Human remains have not been found in or below the diluvial deposits in any part of Europe,—nor have they yet been met with in the tertiary strata of any other part of the world.

That man and his contemporary species are but recent inhabitants of the earth, is one of the fundamental truths of geology. That Volume which reveals the moral history of our race announces the same fact. It is silent respecting former creations, because they are unconnected with that history; but abundant records of them are inscribed on the framework of the globe, in characters so prominent that they seemed placed there to attract our attention. Some pass them by as beneath their notice—some, actuated by a mistaken zeal or a superstitious dread, avert their eyes from them, pronounce harsh judgments on those who attempt to decipher them, and close their ears against the wondrous tale which they relate. And yet those records are fraught with lessons of gratitude, humility, and reverence. They teach us that man, so highly favoured by his Maker, forms a mere atom in the great scheme of creation. The earth and its products are now placed in subjection to us, and we deem in our pride that they were made exclusively for us. We derive benefit, it is true, from former creations, no less than from that which surrounds us. The ancient vegetation, buried beneath miles of strata, ministers to our comfort as well as that which clothes the surface, and the convulsions which have shattered the crust of the earth have placed it within our reach; but if our benefit was the only end proposed in its creation, what purpose do we suppose to have been answered by the extinct races of animals, none of which ever did man service, while some of them, if living now, we should brand as noxious and labour to exterminate—those monsters which basked on the banks of the Wealden rivers, or took their pastime in the waters of the oolitic ocean? Can we doubt that they were called into being as manifestations of the Divine will, designed to display to other intelligent natures than ours, the glories of an omnipotent Creator?

. . . . Nor think, though men were none,
That Heaven would want spectators, God want praise,—

and to beings endued with faculties capable of comprehending the whole plan of creation, of which we see but a part, and that part imperfectly, what delight must have been afforded by the contemplation of the great chain of being thus successively exhibited, when we can find so much to admire in its broken and disjointed fragments! The structure of the earth, as well as the mechanism of the heavens, proclaims the Divinity of the Hand, which made them. The one tells of power and wisdom displayed through the immensity of space, the other tells of the same attributes displayed through the immensity of time; and thus, every bone and shell and leaf disinterred from the dust of the earth, leads our thoughts towards eternity, and the world of spirits, and tells us that, though all things visible are subject to change, they are the work of one invisible and eternal Being, "the same yesterday, to-day, and for ever."

POSTSCRIPT.

The Diluvial question has now assumed a new phase. No. 72 of the third volume of *the Proceedings of the Geological Society*, contains abstracts of three papers by Professor Agassiz, Dr. Buckland, and Mr. Lyell, read since the commencement of the present session, the object of which is to prove that the erratic block period was a period of intense cold, intervening between the present era and that during which the large mammals existed whose remains are buried in and beneath the deposits hitherto called diluvial. It is supposed by these authors, that during this glacial period the temperate regions of Europe, and all countries where unstratified gravel is found, were overspread with glaciers and sheets of ice, like those now existing in Greenland; that the till or unstratified boulder clay was produced by the trituration of ice upon the surface of the rocks; that the rounded, polished, and striated condition of that surface was caused by the descent of the glaciers; that the mounds of debris found in many of the highland valleys of England, Scotland, and Ireland, are lateral or terminal moraines left by them in their retreat; that the angular blocks occurring on the surface of the rounded materials, were deposited in their present position by the melting of the ice; that the disappearance of large bodies of ice produced enormous debacles and considerable currents, by which erratic blocks were conveyed on masses of ice in diverging directions, and by which the materials of the moraines were rearranged in the stratified sand and gravel which covers the till.

This theory was first announced by M. Agassiz as the result of the study, during five years, of the glacial phenomena of Switzerland, by which he was led to the conclusion that the glaciers of that country had once been more extensive; that they did not descend from the summits of the mountains to the plains, but are the remaining portions of sheets of ice which at one time overspread the flat country. Extending his observations to Great Britain and Ireland, he discovered evidence of the former existence of glaciers in those countries, and his observations have been extended and confirmed by Dr. Buckland and Mr. Lyell.

I have long contended, in opposition to Mr. Murchison and Mr. Lyell, that the erratic blocks accompanying marine shells in Wales, Lancashire, Cheshire, Shropshire, and Ireland, were not deposited by melting icebergs on the floor of a sea, which, after remaining submerged during a long course of ages, was converted into dry land by movements of elevation; but that they were spread by marine currents of extraordinary energy and short duration over the surface of pre-existing land,—and I have now no objection to add, over land covered with ice.

Though satisfied of the facilities afforded by conveyance on ice as a means of surmounting some of the difficulties connected with diluvial phenomena, I objected to Mr. Murchison's hypothesis because the conchiferous gravel of the district before mentioned afforded none of those proofs of long submergence and gradual accumulation which are to be found in all other regular submarine strata, and because ice was just as necessary for the transport of Irish detritus to Caernarvonshire, and of Snowdonian boulders to the southward of that chain over great surface inequalities, as for the conveyance of Cumbrian erratics into Worcestershire; if, I observed in an unpublished communication made last year to the Geological Society, it was necessary to fringe the shores of Cumberland with icebergs, it was equally necessary to freeze over the entire surface of the British Islands.

The descriptions by Dr. Buckland and Mr. Lyell, of phenomena, which they attribute to glacial action, in Scotland and Cumberland, forcibly remind me of similar phenomena observed by me in Wales, some of which seem difficult of explanation by aqueous action: the polished, rounded, and striated surface of the rocks,—the direction of the striæ dependent on that of the valleys, and the inclination of the surface—the general subterposition of the till or boulder clay to the stratified deposits composed of the same erratic materials—the terraces analogous to those of Glen Roy, but less regular and extensive, observable on the sides of some of the valleys—the local character of the deposits in the central parts of the chain, varying with the nature of the rocks in each valley—the mounds of debris derived from neighbouring precipices, which could not have reached their present situations without having passed over deep lakes—and the angular blocks sometimes lying on the surface of the more waterworn materials beneath, are phenomena of common occurrence in North Wales.

At the same time, these phenomena are so intimately connected on the northern, eastern, and western sides of the Cambrian chain, with marine shells and fragments of rocks derived from the north-west, or in a direction contrary to that in which the great mass of the detritus with which they are mixed has descended from Snowdonia, as to render it difficult to dispense with irruptions of the sea from that quarter as one of the agencies employed in the rearrangement of the materials of the moraines. The Cumbrian erratics, so abundant on the northern skirts of the Welsh mountains, gradually disappear between St. Asaph and Conwy, and are replaced on the western flanks of the chain by smaller detritus, referrible to Anglesey and Ireland; while, with one exception, and that opposite to the mouth of the Seiont, I could never discover any fragments of the rocks of Caernarvonshire in Anglesey, nor have any boulders from Wales ever been found in Ireland. In the few spots between the Menai and Snowdonia, where marine shells are found, they invariably accompany this detritus from the northwest, and though the two are very abundant, over a small space on the northern flank of Moel Tryfan, and near its summit, they appear scarcely to have had power to surmount its crest, as shells have never been found, and granitic pebbles very rarely, on its southern slopes towards Nantlle Valley, where the detritus is local, and the phenomena which prevail are such as are considered indicative of glacial action.

The magnitude of waves required to waft these shells and erratics to such a height has been urged as an objection to their having been drifted over inequalities of surface like those represented in fig. 197, but if we suppose it reduced by a covering of ice, to an inclined plane, rising about one in twenty-two, or 1392 feet in six miles, while the surface of the Irish seas was as much loaded with ice as those of Greenland, waves of much less power than would otherwise be necessary, produced by oscillations of the bed of the sea, and accompanied by oscillations of the land, may have driven masses of ice, some of them charged with the detritus of Anglesey and Ireland, and with marine shells, up this slope. At the same time, the pressure of ice upon the surface of a rock shattered by frost may have produced the layer of angular debris interposed between the shelly sand and gravel and the rock. Similar masses of angular fragments of the subjacent rock, enveloped in the boulder deposits, and often associated, as in fig. 196, with a polished and striated surface, may be ascribed to the same agency.

M. Agassiz does not expect his glacial theory at once to receive the general concurrence of geologists. Strong evidence has certainly been adduced in support of it; but whatever may be its ultimate fate it possesses this merit, that by its boldness, its novelty, and its plausibility, it will attract more attention to the phenomena of erratic gravel than they have hitherto received, and the investigations and discussions to which it will give rise must tend to elicit the true history of these deposits. It has already produced much animated discussion in the Geological Society, and there is little danger of its being too hastily adopted. Though supported by illustrious names, names as illustrious are ranged on the opposite side:

> And many a banner will be torn,
> And many a knight to earth be borne,
> And many a sheaf of arrows spent,
> Ere Scotland's king will cross the Trent.

GLOSSARY.

Acephalous. Destitute of head. A, privative, κεφαλη, a head.

Algæ. Marine plants of one of the lower orders.

Alluvium. Gravel, sand, &c. washed away from its original situation.

Aluminous. Containing the earth Alumina, which combined with sulphuric acid and potassa, constitutes *alum.*

Amygdaloid. Trap rock containing mineral fragments. Αμυγδαλη, an almond.

Amorphous. Wanting a definite or regular form. A, privative, μορφη, form.

Anticlinal Axis. See p. 173.

Arenaceous. Resembling, or containing, sand.

Argillaceous. Composed in part of clay, or aluminous earth.

Basalt. A compound rock, composed of felspar and augite, and frequently found in prismatic columns.

Basin. A series of strata deposited upon more ancient rock, like the coats of mud at the bottom of a lake.

Bitumen. A mineral substance, somewhat resembling pitch, and found existing in many varieties of coal.

Boulder. A rounded mass of stone, removed from its original position.

Botryoidal. Covered with smooth, spheroidal masses. Βοτρυς, a bunch of grapes, ειδος, form.

Breccia. Angular fragments of rock or other substance cemented together. When the fragments are of bones, it is termed *osseous.*

Calcareous. Containing carbonate of lime.

Calcaire grossier. A series of eocene strata found in the Paris basin.

Capillary. Hair-like; resembling hair.

Cataclysm. A flood or deluge. Κατακλυσμος, a flood.

Cellular. Containing cells, or small vacant spaces.

Cephalopoda. Mollusca, whose organs of motion are placed round the head. Κεφαλη, a head, πους, a foot.

Cetacea. Marine animals of the whale class, mammiferous and vertebrated.

Chalk. White earthy carbonate of lime, the last of the secondary strata.

Coleoptera. Four-winged insects, whose upper pair of wings serves as a sheath for the lower. Κολεος, a sheath, πτερον, a wing.

Conchoidal. A term applied to the fractures of minerals when rounded, even and smooth.

Conformable. Where the planes of one series of strata are parallel to those of another, they are said to be *conformable,* where otherwise, *unconformable.*

Conglomerate. Pebbles and washed fragments, cemented together by other mineral matter.

Cosmogony. A general term applied to theories and speculations regarding the origin of the world, and in this distinguished from geology, which considers the changes that have since taken place in its constituent parts. Κοσμος, the earth, γονη, birth or origin.

Crop. Miners say that a vein "crops out" when it makes its appearance at the surface.

Crustacea. A class of animals which periodically change their shells. Such are the lobster, the crab, &c.

Cyperaceæ. A class of plants, comprising the cyperus, carex, &c.

Delta. Alluvial land deposited by a river at its mouth. The stream is frequently divided by this deposit, and flowing on each side of it, gives it the form of the Greek Δ.

Denudation. Strata previously below the surface, are often uncovered by floods and other natural causes, and this act is termed *denudation.*

Dike. A mass of igneous rock apparently injected into a split or a rent in stratified rocks, thus interrupting the continuity of the strata. Dikes are frequently harder than the other mineral substances that enclose them, suffering less by disintegration, and hence we often find them projecting like a wall beyond the surface.

Diluvium. Loose beds of sand or gravel, considered by some geologists to have been caused by a deluge.

Dip. Variation from the horizontal line, measured in degrees of a circle.

Disintegrated. In detached portions; worn, or broken in pieces.

Eocene. See p. 359.

Escarpment. A precipice terminating an elevated ridge of land.

Estuary. The mouth of a river where the fresh water mixes itself with the brine.

Exuviæ. Integuments of animals and insects which are periodically cast off. Applied in Geology to any fossil remains.

Fault. When mineral masses are displaced by subterranean movements, a rending may take place, and the strata on one side of the rent may be lifted higher than those on the other, so as to be no longer continuous with them. This is a *fault.* Either the two sides may be pressed together, or a chasm may be formed by their separation and subsequently be filled up by loose materials. See also p. 177.

Fibrous. Consisting of fibres, a term applied to minerals which appear to be composed of slender, hair-like portions, as most varieties of Asbestus, &c.

Foraminifera. A class of microscopic shells, whose cells communicate by small openings or *foramina.*

Formation. A group of rocks, supposed to be of equal antiquity.

Friable. Easily broken or comminuted.

Gasteropoda. A class of testaceous animals in which the foot is attached to the body. Γαστηρ, the belly, πους, a foot.

Geode. A hollow mass of stone, often crystallized in the interior.

Geology. The study of the changes which have taken place in the structure of the earth, since its creation. Γη, the earth, λογος, a discourse.

Glacier. Accumulated masses of snow and ice, found on many mountains, but chiefly on the Alps.

Glacis. A slope, where the descent is too gradual to be perceptible.

Gramineæ. A class of plants containing corn, wheat, grass, &c. distinguished from the *cyperaceæ*, which they resemble, by having hollow stems, and the sheathing part of the leaf slit, which is not the case in the other class.

Grit. Coarse-grained sandstone.

Hypogene Rocks. See p. 475.

Igneous Rocks. Rocks that have been melted by subterranean heat.

Infusoriæ. Minute animalcula, so named because some of their species were first observed in vegetable and other infusions. They are found at the surface, and at the bottom of pools, in sewers, and in any stagnant water.

Iridescent. A play of colours visible on the surface of some minerals, and usually produced by a thin film of metallic oxide, arising from the decomposition of the mineral.

Lacustrine. Produced through the agency of lakes.
Lamellar. Applied to minerals which split into thin plates with two parallel sides.
Lava. The melted mass which issues from a volcano during an eruption.
Lias. A group of secondary limestones. See p. 306.
Lithodomi. Mollusca which cut, or dissolve holes for themselves in rocks. Λιϑος, stone, δῶμα, a house.
Loam. Clay and sand mixed.
Lycopodiaceæ. A class of plants, of which the modern species resemble the ground pine. Some fossil species are as large as modern trees.

Madrepore. Properly a genus of corals, but the term is often extended to other corals than those included in the true genus.
Mammiferous. Giving suck to its young. The class Mammifera includes all warm-blooded quadrupeds, and the whale, the seal, the porpoise, &c.
Marl. Composed of lime and clay, or carbonate of lime, silex, and alumina. Marls are generally soft, and the hard marls fall to pieces by exposure.
Marsupialia. A tribe of quadrupeds of greater antiquity than any of the Mammifera. They take their name from having a pouch attached to the belly in which their young are carried.
Metamorphic Rocks. See p. 195.
Miocene. See p. 359.
Muschelkalk. A limestone belonging to the red sandstone group.

Nodular. Consisting of, or containing nodules, roundish, irregular masses.
Nucleus. The interior portion, or solid core, of a body. If a pebble be encrusted with mineral matter from a petrifying spring, it constitutes the nucleus of the resulting mass.

Oolite or **Roe Stone.** A limestone composed of rounded grains resembling the roe of a fish. It gives its name to a large group of strata. Ωον, an egg, λιϑος, stone.
Organic Remains. Fossil remains of *organized* natural productions, or those belonging to the animal and vegetable kingdoms.
Outlier. A name applied to a stratum found at some distance from the others that belong to the same formation.

Pliocene. See p. 359.
Plutonic Rocks. Rocks supposed to have been produced by the agency of heat, below the surface of the earth. These are granite, porphyry, &c.
Pseudomorphous. Applied to minerals which assume *false forms* (whence the name) in consequence of solidifying in the cavities of other minerals. Thus quartz may be found in cubes, and carbonate of zinc frequently assumes the form of dog's tooth spar. Ψευδης, false, μορφη, form.
Puddingstone. See *Conglomerate.*
Pulverulent. Friable; easily reduced to powder.
Pumice. A whitish spongy substance that rises to the surface of lava. It is obsidian, rendered frothy by air-bubbles.

Radiated. Diverging from a centre, like the sticks of a fan.
Reniform. Kidney-shaped; having two spreading lobes.
Ruminantia. Animals that chew the cud, or, after swallowing their food, bring it a second time into the mouth for mastication.

Sandstone. Rock composed of sand of any kind.

Saurian Animals. Those of the lizard tribe. Σαῦρος, a lizard.

Schist. A general name applied to a class of minerals resembling slate, but differing from it in not being susceptible of indefinite lamination.

Scoriæ. Volcanic cinders.

Seam. A thin stratum separating two that are thicker.

Sedimentary Rocks. Rocks formed by the deposition of matter, either dissolved or mechanically suspended in water.

Shale. A variety of clay slate, which does not, like the slate used for the roofs of houses, split readily into lamina.

Silt. The finely comminuted mud which is carried on by flowing water, composed chiefly of sand and clay.

Solfatara. A volcanic opening emitting sulphureous and other vapours.

Stalactite—Stalagmite. When water, holding mineral matter in solution, drops from the roof of a cavern, it forms a pendent, icicle-like concretion, which is a *stalactite.* The similar concretion built up from below by the falling water is a *stalagmite*, and these frequently unite to form massive columns. Stalactite, σταλαζω, to drop—Stalagmite, σταλαγμα, a drop.

Strata. Accumulated beds of matter, in most cases, but not always, deposited by water, and having their dividing planes more or less parallel. Stratified rocks constitute a great portion of the earth's crust. For their characters, divisions, &c. see p. 208.

Stratified. Arranged in strata.

Striate. Crystals are said to be *striate* when *striæ*, or small channels are visible on their surfaces.

Subapennine. Low hills which border the Apennines. Applied to a series of older pliocene strata.

Syenite. A variety of granite originally brought from Syene in Egypt.

Synclinal Axis. See p. 173.

Talus. The pile of sand and fragments, accumulated at the bottom of a steep rock, from which they are detached by the influence of the weather.

Trachyte. Lava composed chiefly of glassy felspar; sometimes containing augite and hornblende. Τραχυς, rough.

Translucent—Transparent. When a body is so clear that objects may be discerned through it, it is *transpurent.* If it merely transmits a few rays of light, and objects cannot be distinguished through it, it is *translucent.*

Trap. A general name for a class of volcanic rocks, having felspar, hornblende, and augite for their bases. Basalt, dolorite, and amygdaloid are among its varieties.

Travertin. A hard, concrete, and semicrystalline limestone, deposited from water.

Tufa, Volcanic. A composite rock, consisting of volcanic fragments, chiefly those of *scoriæ*, which see.

Unconformable. See *Conformable.*

Unctuous. Applied to minerals which are greasy to the touch, as plumbago.

Vein. A rent or fissure in either stratified or unstratified rocks, filled up by mineral matter. The term is often improperly applied to coal, which is deposited in *beds* or *seams.*

Vesicular. Applied to minerals which contain bubbles, or small, bladder-like cavities.

Vitreous. Glass-like; with glassy lustre.

Zoophyte. The class of zoophytes, or animal plants, including the corals, sponges, etc., because, while formed somewhat like plants, and attached to the ground, they are the abodes of animals. Ζῶον, animal, φυτον, plant.

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